Acta Psychologica 269 (2026) 107455

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Eye-gaze-driven games to support oculomotor skills in young adults with cerebral palsy using eye-tracking technology: a multiple case study

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ARTICLE INFO

Keywords:
Cerebral palsy
Eye-tracking technologies
Eye-gaze-driven games
Oculomotor control

ABSTRACT

Background: Assistive technology such as eye-tracking systems can enhance communication, participation, and self-efficacy in individuals with motor impairments. However, in people with cerebral palsy (CP), visual and oculomotor impairments may limit their effective use and reduce participation in daily activities.
Purpose: This multiple case study aimed to investigate the effects of eye-gaze-driven games on oculomotor and visual exploration skills in adults with CP, and to assess the usability of the intervention, with the broader goal of facilitating the use of eye-tracking systems as communication tools.
Materials and methods: Three young adults with CP participated in a multiple case study. They underwent a pre- and post-intervention visual assessment using eye-tracking metrics. The intervention consisted of training oculomotor abilities through four eye-gaze-driven games for 60 min per session, across five sessions within one week. Usability was assessed using the System Usability Scale. Quantitative data were summarized using descriptive statistics, while visual performance was analyzed qualitatively.
Results: Improvements in fixation precision and visual exploration were observed in two out of three participants, supported by qualitative analysis of gaze patterns. Participants also reported improvements in fixation quality and visual field, along with enhanced self-perceived oculomotor abilities. One participant showed improvement in eye-tracker calibration. Usability scores ranged from 60 to 87.5, indicating good usability.
Conclusion: These preliminary findings suggest that eye-gaze-driven games may represent an engaging approach to train oculomotor function in individuals with CP and may serve as a preparatory step for the use of eye-tracking assistive technologies.

1. Introduction

Cerebral palsy is a neurodevelopmental condition affecting movement and posture (Dan et al., 2026) with a prevalence of approximately 1.5–3 cases per 1000 live births (Stavsky et al., 2017). It is caused by non-progressive disturbances of the developing brain occurring during the pre-, peri-, or postnatal period (Abd Elmagid & Magdy, 2021; Dan et al., 2026). The phenotype of cerebral palsy is heterogeneous and may involve motor, sensory, cognitive, and communication impairments, as well as secondary complications of varying severity (Bax et al., 2005;Dan et al., 2026; Rosenbaum et al., 2007). These impairments can significantly affect participation in daily activities and overall quality of life for individuals with cerebral palsy and their caregivers (Dan et al., 2026; Rosenbaum et al., 2007).

Assistive technology can support communication and interaction in individuals with motor impairments (Borgestig et al., 2017; Caligari et al., 2013; Caltenco et al., 2012; Hwang et al., 2014). Eye-tracking devices translate gaze direction into cursor movement on the screen, allowing users to navigate and select specific on-screen elements (Karlsson et al., 2018). In individuals with limited voluntary motor control, eye movements may represent one of the most effective ways to interact with the environment and digital interfaces (Borgestig et al., 2016; Caligari et al., 2013).

Individuals with cerebral palsy frequently experience visual (Dutton et al., 2014) and oculomotor impairments (e.g., Almutairi et al., 2018; Lampe et al., 2014). Previous studies in children with tetraplegic

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https://doi.org/10.1016/j.actpsy.2026.107455
Received 19 September 2025; Received in revised form 1 July 2026; Accepted 13 July 2026
Available online 15 July 2026

cerebral palsy have reported a high prevalence of unstable fixation, impaired smooth pursuit movements, and altered saccadic movements (e.g., Fazzi et al., 2012). Similarly, studies in adults with cerebral palsy have shown longer reading times, as well as an increased number of saccades, fixations, and regressions compared to healthy individuals (Lampe et al., 2014). These deficits may negatively affect the effective use of eye-tracking technologies, reducing their potential benefits.

In recent years, several studies (Bekteshi et al., 2022, 2020; Borgestig et al., 2016) have investigated the use of eye-gaze-based activities to improve oculomotor skills in children with cerebral palsy and spinal cord injury. Overall, findings suggest that such training may improve oculomotor performance in the paediatric population. Previous research has focused on children, predominantly with dyskinetic cerebral palsy. Evidence in the adult population remains limited, particularly for individuals with heterogeneous functional profiles.

Within this context, the present study aims to explore how oculomotor and visual exploration skills may change following training with eye-gaze-driven games in adults with spastic-dystonic cerebral palsy and different functional profiles. To this end, pre- and post-intervention visual performance was compared. Furthermore, the usability of the proposed intervention was examined to explore its potential as a facilitator for the use of eye-tracking assistive technologies.

2. Methods and materials

2.1. Participants

Participants were recruited among the students and staff of the University of Milano-Bicocca. Inclusion criteria were: having a clinical diagnosis of cerebral palsy, Italian nationality, and aged over 18 years. No prior experience with eye-tracking technology was required. The functional profile of participants with cerebral palsy was determined using the Visual Function Classification System (VFCS) (Baranello et al., 2020; Bekteshi et al., 2020), Gross Motor Function Classification System - Expanded and Revised (GMFCS, E&R) (Palisano et al., 2008), Manual Ability Classification System (MACS) (Eliasson et al., 2006), Communication Function Classification System (CFCS) (Hidecker et al., 2011), and the Viking Speech Scale (VSS) (Pennington et al., 2013). Exclusion criteria included: present or past psychiatric disorders, a history of photosensitive epilepsy, and severe nystagmus. The type of cerebral palsy, chronological age, sex, education, and previous experience with eye-tracking were also recorded.

2.2. Ethics

This study has been approved by the local ethical committee of the University of Milano-Bicocca (approval no: 905, approval date: 11 November 2024). The participants were assured that all personal information and responses would be kept confidential and that their information would be used only for this study. Participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki.

2.3. Study design

The study adopted a multiple case study design involving three participants and was structured in three phases. At baseline (T0), researchers collected the demographic data and the participants' functional profile. Participants then completed a series of visual tests using an eye-tracking device to establish their initial level of oculomotor performance (Fig. 1).

Afterwards, the intervention phase started, during which participants engaged four eye-gaze-driven games from Look Lab software by ThinkSmartbox® for 1 h per session, across five sessions over one week (Table 1; Fig. 2). All participants completed the same set of eye-gaze-driven games; however, the order of administration was randomized to control for potential order effects.

At the end of the intervention phase (T1), participants performed the

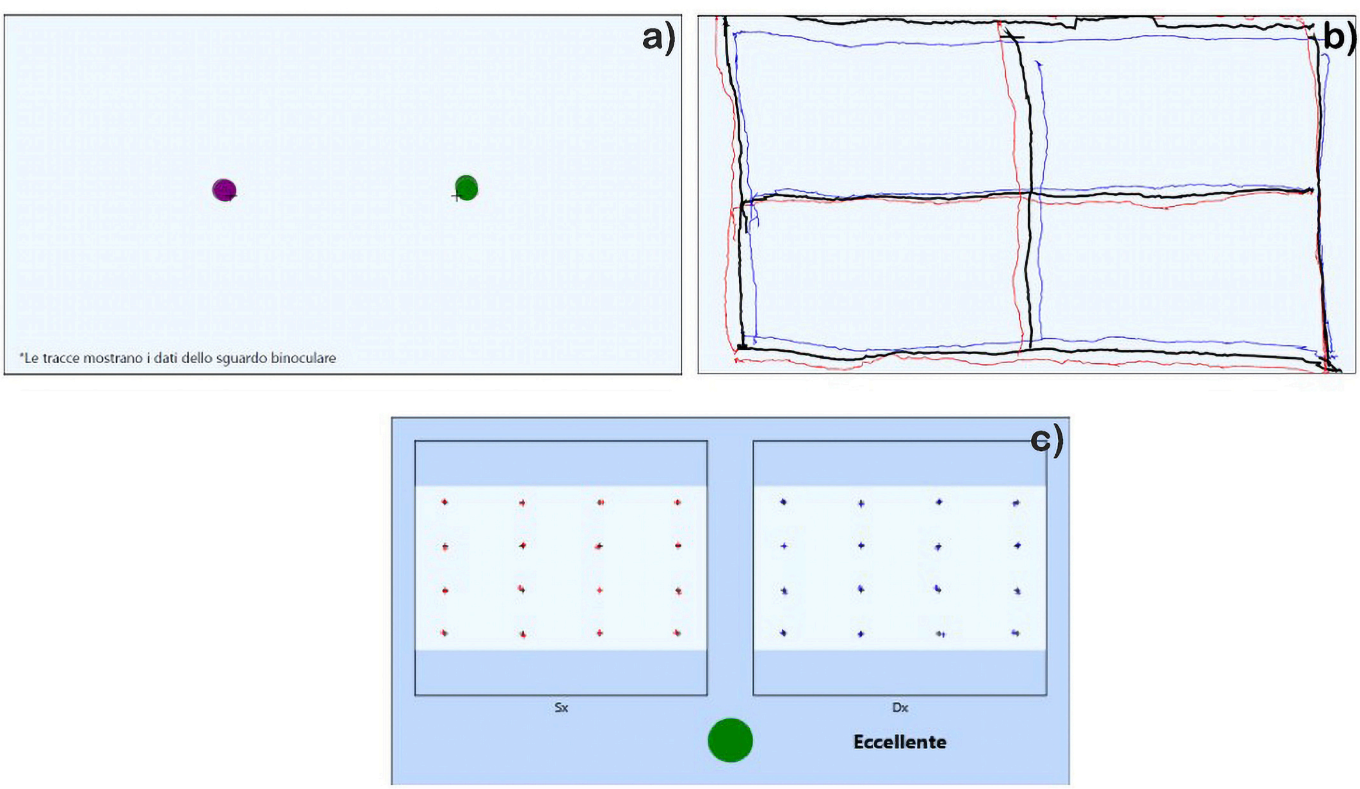

Fig. 1. Screenshots of the three tests used: a) Fixation test; b) Visual field test; c) Calibration.

Table 1
Selected games' features.

Activity	Exploration	Tracking	Sustained attention	Dwelling	Reaction times	Horizontal control	Vertical control	Fixation precision	Problem solving
Splat	✓			✓	✓			✓	✓
Space shoot		✓		✓				✓	
Hoops		✓			✓	✓			
Pipe dodge			✓		✓		✓		

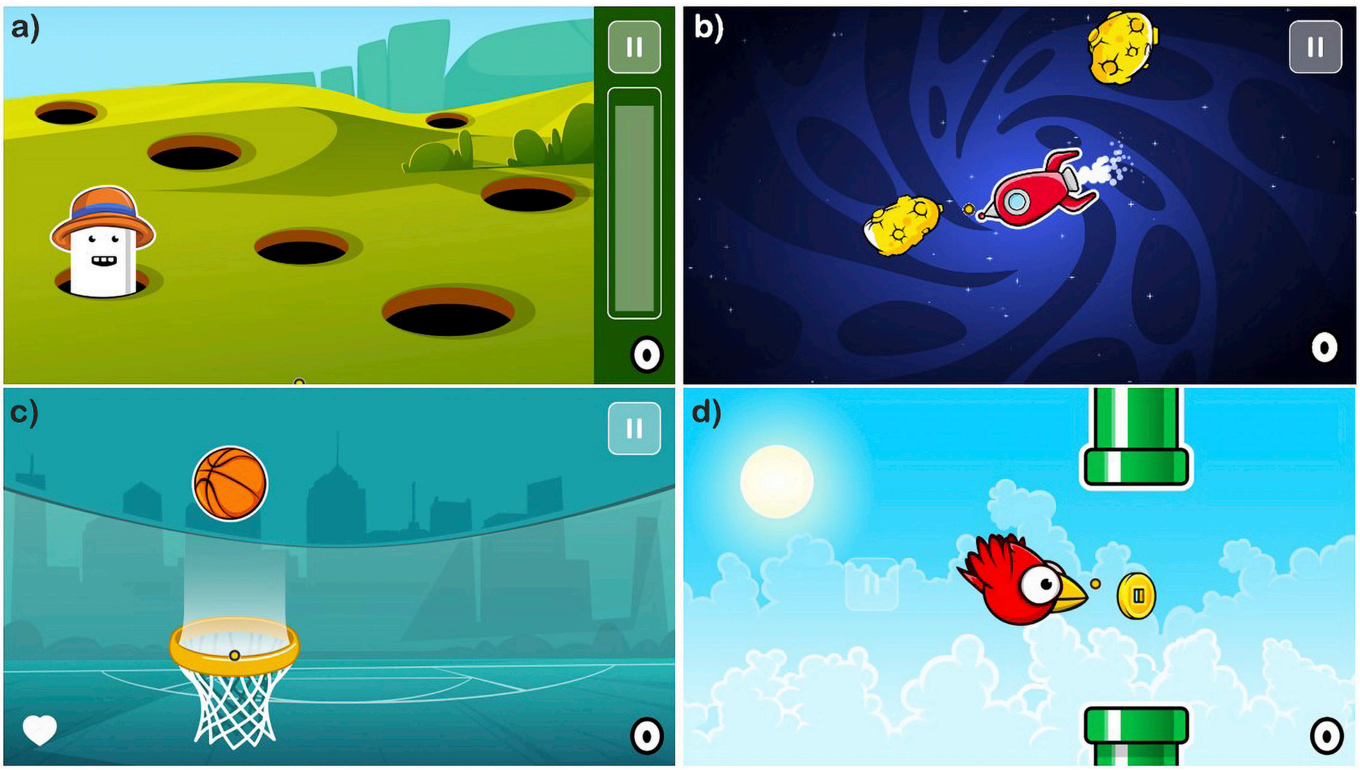

Fig. 2. Screenshots of the four eye-gaze-driven games used from "Look Lab" software by ThinkSmartbox®: a) Splat; b) Space shoot; c) Hoops; d) Pipe dodge.

same visual tests they completed at the baseline. Furthermore, participants also completed the System Usability Scale (Brooke, 1996; Lewis, 2018; Sauro & Lewis, 2016) to collect information regarding the system's usability.

Given the exploratory nature of this study and its case-based design, a small sample size was considered appropriate to enable in-depth analysis of individual responses rather than statistical generalization. This design allows detailed within-case analysis of oculomotor changes following the intervention.

This study was reported in accordance with the CARE (CAse REport) guidelines for case report research.

2.3.1. *Equipment*

The protocol was implemented using a 15.6-in. laptop (Intel Core i7-6700HQ CPU @ 2.60GHz, 16 GB RAM, NVidia GeForce GTX 950 M) running Windows 11, an "Alea IntelliGaze CAM30NXT" eye-gaze camera, and "Look Lab" software (ThinkSmartbox®, UK). The eye-tracking system consisted of the CAM30NXT (Alea Technologies®, Germany), which uses infrared corneal reflection and pupil tracking with a sampling rate of 60 Hz. Head movements are compensated, and eye movements were recorded binocularly using IntelliGaze software (version 11). Participants were seated approximately 60 cm from the monitor to ensure optimal pupil detection. Before each experimental session, a standardised calibration procedure was performed. The eye-tracking system was used as a mouse emulation interface to allow participants to interact with on-screen activities. Look Lab software (ThinkSmartbox®, UK) consists of 38 eye-gaze-driven games for all ages that can help to develop different skills: a) exploration, b) cause & effect, c) tracking targets, d) sustained attention, e) dwelling, f) choice making, g) reaction times, h) memory, i) horizontal gaze control, j) vertical gaze control, k) fixation precision, l) problem-solving. Most activities are available in different difficulty levels (e.g., easy or standard) and with varying graphical complexity (e.g., minimal or detailed). Furthermore, the software provides visual outputs such as heat maps, which display gaze distribution and fixation duration.

2.3.2. *Visual assessment*

All participants completed a visual assessment at T0 and T1 using IntelliGaze v11 software to evaluate changes following the intervention. Eye-tracking metrics were analyzed using Intelligaze v11 software, which includes the "Gaze Assistant", a tool designed to measure users' gaze interaction abilities and generate eye-tracking metrics. The software allows the creation of user profiles and the assessment of fixations, visual field, blinks, and calibration accuracy. The visual assessment was conducted exclusively using IntelliGaze software. The resulting metrics were analyzed descriptively, combining quantitative outputs (e.g., fixation precision and duration) and qualitative observations (e.g., gaze trajectories).

Specifically, the fixation test (Fig. 1a) evaluates the user's ability to detect and look at a target displayed on the screen. During the fixation test, two spots appeared consecutively in two different positions on the monitor, repeated three times, and the participant was instructed to look at them. Leftward and rightward fixation precision, as well as average fixation time, were measured. Fixation precision was defined as the deviation between the points fixated by the user and the actual location of the stimuli on the screen; a value lower than 100 pixels (px) indicates acceptable precision, meaning that the user responded to the stimuli. Average fixation duration was calculated by identifying fixations as gaze events lasting longer than 100 ms. Indeed, fixations can be defined as periods during which the line of gaze remains within a small spatial window (e.g. 0.5 deg. circle) for at least 50 ms (e.g., Bricolo et al., 2015).

The visual field test (Fig. 1b) assessed the ability to pursue a target moving across the entire screen along three horizontal and three vertical trajectories. Three different coloured lines are displayed: a red line representing the left eye, a blue line representing the right eye, and a black line representing the combined gaze of both eyes. This allows the identification of potential difficulties for each eye individually.

The blink test evaluates the users' blinking behavior. In detail, the system detects the average blink duration while looking at the target.

Finally, the last test consisted of a calibration procedure (Fig. 1c), in which participants were required to fixate on targets presented in a predefined sequence. The system can be calibrated for one or both eyes; in this study, binocular calibration was used.

A report summarizing the data obtained from the aforementioned tests can be generated for each user profile.

2.3.3. Training with eye-gaze-driven games

Four eye-gaze-driven games were selected from Look Lab software (ThinkSmartbox®, UK). Their features are reported in Table 1. The activities were selected based on the specific eye-gaze skills they were designed to train, including exploration, in which users are encouraged to explore all areas of the screen; tracking targets, where users are required to look at one or more targets and follow their movements; sustained attention, which requires users to focus on specific areas of the screen while ignoring distractions; dwelling, aimed at developing the ability to fixate on a target; reaction time, where users must respond quickly to changes on the screen; horizontal gaze control, requiring users to move their gaze from left to right and vice versa; vertical gaze control, requiring users to move their gaze up and down and vice versa; fixation precision, aimed at improving the accuracy of gaze; and problem-solving, where users must plan their gaze movements to complete the task.

In the splat game (Fig. 2a), users are required to hit the worms that appear on the lawn using a hammer. In detail, they must explore different areas of the screen (exploration), fixate on each hole from which a worm appears (fixation precision), and maintain their gaze long enough to hit it (dwelling). Furthermore, users must respond promptly to the appearance of the worms before they disappear and before the time expires, while avoiding bombs (reaction time and problem-solving).

In the space shoot game (Fig. 2b), users must shoot asteroids before they collide with the spaceship and collect stars to earn points. In particular, they are required to follow the movement of the asteroids (tracking), maintain focus on the closest asteroid as others appear (sustained attention) and fixate on it long enough to shoot it (dwelling).

In the hoops game (Fig. 2c), users must catch as many balls as possible while avoiding bombs. Precisely, they are required to track the ball (tracking) as it moves horizontally across the screen (horizontal control) and catch it with a basket before it falls (reactions).

Finally, in the pipe dodge game (Fig. 2d), users must guide a bird between the pipes while collecting as many coins as possible. Specifically, they must focus on the bird rather than the pipes (sustained attention), move it up and down (vertical gaze control), collect coins, and avoid collisions with the pipes (reaction time).

For each activity, either an easy or a standard difficulty level can be selected. In the easy mode, games are typically slower, with larger targets, speed remains constant, there is no time limit, and there is no fixed number of attempts before the game ends. In the standard mode, the game becomes progressively more challenging; targets are smaller, and there is either a time limit or a limited number of attempts before the game ends. In each session of the study, participants first completed 10 min of eye-gaze-driven games in easy mode, followed by standard mode, whose duration varied depending on the participant's abilities.

Additionally, either a minimal or a detailed display mode can be selected. In the minimal mode, distractions are reduced, and the contrast between objects and background is high. In detailed mode, objects and backgrounds are more colourful, and additional information such as score and remaining time is displayed. In this study, the detailed mode was used for all participants.

Daily training sessions were scheduled in agreement with each participant and were conducted under the supervision of the researcher. Each training session lasted approximately one hour and consisted of an initial setup, calibration, and gameplay phases. The order of the eye-gaze-driven games was randomized to avoid any order effects.

2.3.4. Usability

At the end of the T1 phase, usability was assessed using the Italian version of the System Usability Scale. (SUS; Table 2) (Brooke, 1996; Lewis, 2018; Sauro & Lewis, 2016). The SUS consists of a 10-item questionnaire based on a Likert Scale, with five response options ranging from "strongly agree" to "strongly disagree". Each item is scored on a scale from 1 to 5. The sum of the responses is then converted into a total score ranging from 0 to 100; with scores above 68 generally considered indicative of "good" to "best imaginable" usability.

2.4. Data analysis

Descriptive statistics were used to provide general information on the study outcomes (means and standard deviations). Regarding the visual abilities, participants' pre- and post-intervention performance was compared and analyzed qualitatively by comparing eye-tracking outputs (e.g. fixation patterns, visual field trajectories, and calibration performance). Concerning the system usability, SUS score were summarized descriptively, and their corresponding usability classifications were reported and interpreted. Finally, participants' impressions, opinions, and suggestions regarding the system used were analyzed descriptively.

3. Results

The results section presents the content and the qualitative findings

Table 2
English and Italian versions of the System Usability Scale.

Original English version	Italian version
I think that I would like to use this system frequently	Penso che mi piacerebbe utilizzare questo sistema frequentemente
I found the system unnecessarily complex	Ho trovato il sistema complesso senza che ce ne fosse bisogno
I thought the system was easy to use	Ho trovato il sistema molto semplice da usare
I think that I would need the support of a technical person to be able to use this system	Penso che avrei bisogno del supporto di una persona già in grado di utilizzare il sistema
I found the various functions in this system were well integrated	Ho trovato le varie funzionalità del sistema bene integrate
I thought there was too much inconsistency in this system	Ho trovato incoerenze tra le varie funzionalità del sistema
I would imagine that most people would learn to use this system very quickly	Penso che la maggior parte delle persone potrebbero imparare ad utilizzare il sistema facilmente
I found the system very cumbersome to use	Ho trovato il sistema molto macchinoso da utilizzare
I felt very confident using the system	Ho avuto molta confidenza con il sistema durante l'uso
I needed to learn a lot of things before I could get going with this system	Ho avuto bisogno di imparare molti processi prima di riuscire ad utilizzare al meglio il sistema

from the performed visual tests at T0 and T1, the usability interview, and the lessons learned from our participants for future training applications to other individuals with cerebral palsy.

3.1. Sample demographics

Three participants (one female and two males) with spastic-dystonic cerebral palsy, who met the inclusion/exclusion criteria, were enrolled in the study. All participants completed the experimental procedure, and no one was discarded. Participants' characteristics, including functional profile and eye-tracking experience, are presented in Table 3. None of the participants had intellectual deficits. All participants graduated; two of them were employed full-time; instead, one participant was completing her postgraduate training. Two participants had no vision problems, while one wore eyeglasses for myopia and astigmatism (refractive prescription: left eye: sph. -5.50, cyl −2.50 × 15°; right eye: sph. -9.00, cyl −4. 00 × 165°). None of the participants had previous experience with eye-tracking technology.

3.2. Visual performances pre- and post-intervention

Below, the individual visual performances of the participants are presented. Images on the left refer to the baseline (T0) assessment; whereas those on the right refer to the post-intervention phase (T1). The results of the blink test are not reported, as they did not function properly for two out of three participants at T0.

3.2.1. P01 pre- and post-intervention assessment

3.2.1.1. Fixation test. P01 showed low fixation precision at T0, particularly for the left target (Fig. 3a). At T1 (Fig. 3b), fixation precision improved for the left target, while a slight decrease was observed for the right target. Regarding average fixation duration, an increase was observed following training with eye-gaze-driven games.

3.2.1.2. Visual field test. The visual field test (Fig. 4) showed poor performance for participant P01, at both T0 and T1 (see the discussion).

3.2.1.3. Calibration test. Regarding the calibration test, P01 showed improvement following training with eye-gaze-driven games. Specifically, calibration quality improved from “very poor” at T0 (Fig. 5a) to “poor” at T1 (Fig. 5b).

3.2.2. P02 pre- and post-intervention assessment

3.2.2.1. Fixation test. P02 showed high fixation precision at T0 (Fig. 6a). At T1 (Fig. 6b), fixation precision decreased, although the values remained within a good range. A reduction in average fixation duration was also observed following training with eye-gaze-driven games.

3.2.2.2. Visual field test. Visual field performance was successfully assessed at both T0 (Fig. 7a) and T1 (Fig. 7b). An improvement in line tracing was observed following training with eye-gaze-driven games.

3.2.2.3. Calibration test. No changes were recorded between T0 and T1 (Fig. 8). Calibration performance was already excellent at T0.

3.2.3. P03 pre- and post-intervention assessment

3.2.3.1. Fixation test. At T0 (Fig. 9a), P03 showed high fixation precision for the right target and lower precision for the left target. At T1 (Fig. 9b), fixation precision for the left target improved substantially, while that for the right target remained largely unchanged. An increase in average fixation duration was also observed following training with eye-gaze-driven games.

3.2.3.2. Visual field test. P03's visual field test (Fig. 10) showed a substantial improvement in line tracing following training with eye-gaze-driven games.

3.2.3.3. Calibration test. No changes were observed between T0 (Fig. 11a) and T1 (Fig. 11b). Calibration performance was already excellent at T0.

3.3. Participants' usability perception

All participants reported high satisfaction with the usability of the system. According to the System Usability Scale (SUS), one participant achieved a “best imaginable” rating (87.5 points), one an “excellent” rating (77.5 points), and one an “okay” rating (60 points). The overall mean SUS score was 75 points (SD = 13.92), corresponding to a grade “B” according to standard SUS interpretation.

3.4. Participants suggestions

Participants were invited to express their impressions about the eye-tracker system and eye-gaze-driven games. Below, their opinions are reported.

P01: I was excited to try an eye-tracker but found several difficulties due to my eyeglasses. I think people with visual impairments like me should use another eye-tracker system because it was frustrating when the calibration failed. I was looking at the target, but the system did not recognize my eyes. If the system had worked better, I would have enjoyed it more. Overall, I enjoyed participating in this study, and, although fortunately for me, I don't need to use the eye tracker in my daily life, it gave me another perspective on the world of disability.

P02: I think that the easy mode [10 min for each game] was too long, especially if you are planning to use it with children. If you play for several minutes, you can feel slight burning sensations in the eyes, tearing or fatigue. Regarding the game, in my opinion, the graphics were too childish. I think that it will be necessary to implement more difficult games for adults. Despite that, I think that eye-gaze-driven games can be very useful and a fun opportunity for people with severe disabilities who cannot play video games in a standard or adapted way. Finally, I believe the direct connection with the Grid 3 software is beneficial for those who cannot talk. In fact, in this way, they can express their opinions and feelings.

P03: After training with eye-gaze-driven games, I noticed an improvement in my eye precision and concentration. The system is not

Table 3
Participants' characteristics.

Participant	Age (years)	Gender (M/F)	Education	VFCS	GMFCS E&R	MACS	CFCS	VSS	ET experience
Spastic-dystonic cerebral palsy									
P01	37	M	16	I	II	III	II	II	No
P02	31	F	18	I	IV	V	III	III	No
P03	33	M	18	I	III	III	I	II	No

Abbreviations: VFCS, Visual Function Classification System; GMFCS E&R, Gross Motor Function Classification System - Expanded and Revised; MACS, Manual Ability Classification System; CFCS, Communication Function Classification System; VSS, Viking Speech Scale; ET experience, previous eye-tracking experience.

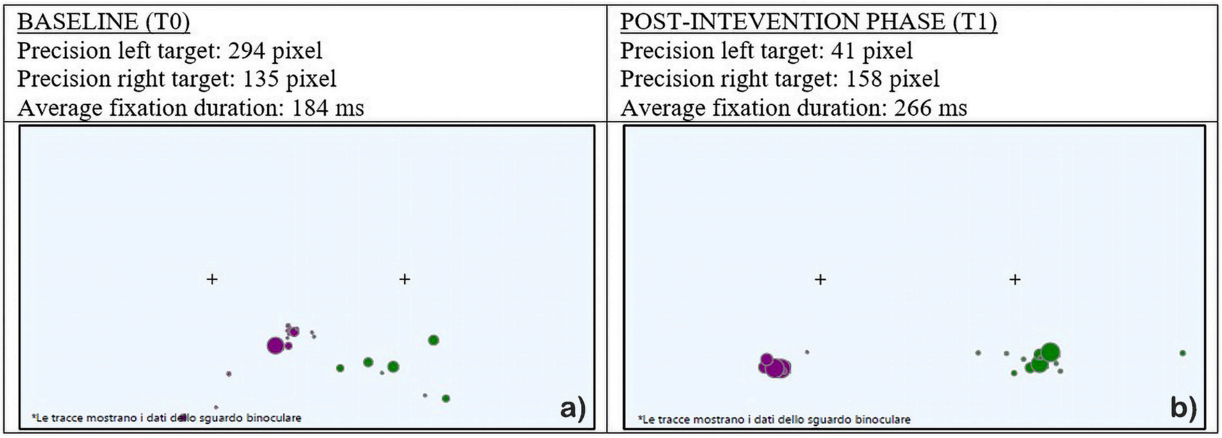

Fig. 3. Screenshot of participant P01's fixation test: a) at baseline (T0); b) at post-intervention phase (T1).

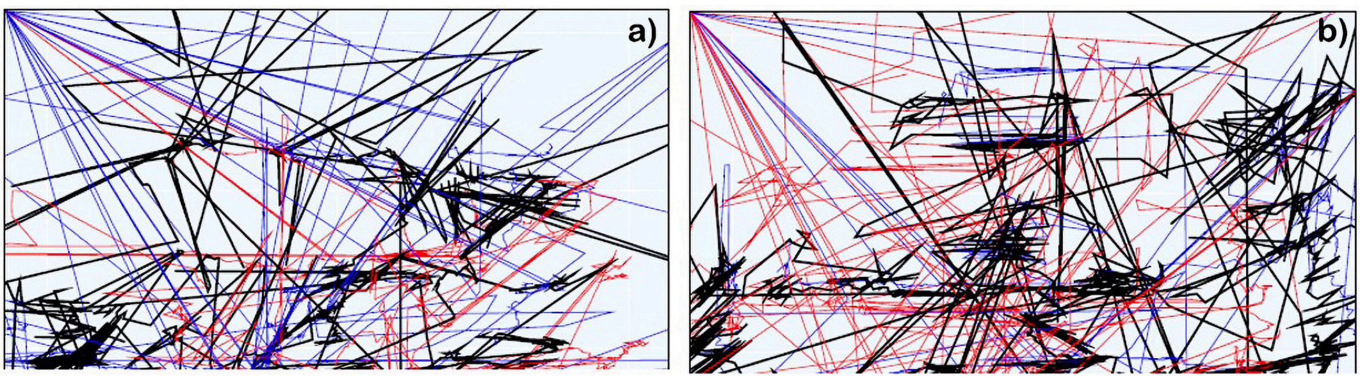

Fig. 4. Screenshot of participant P01's visual field test: a) at baseline (T0); b) at post-intervention phase (T1).

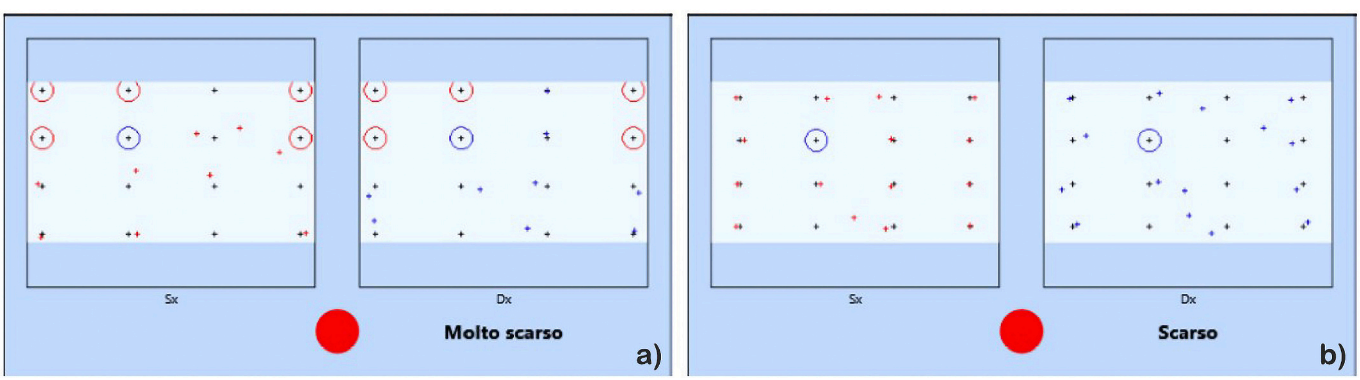

Fig. 5. Screenshot of participant P01's calibration test: a) at baseline (T0); b) at post-intervention phase (T1).

difficult to use, but intuitive. The games, although basic, are quite fun.

4. Discussion

This study aimed to explore how oculomotor and visual exploration skills may change following eye-gaze-based training in adults with cerebral palsy, and to assess the usability of the intervention. For this purpose, three participants were recruited, two (P02 and P03) had no visual impairments, while one (P01) wore glasses to correct myopia and astigmatism. None of them had previous experience with eye trackers. After five training sessions with eye-gaze-driven games, two participants (P01 and P03) showed improvements in fixation tests. At the same time, one (P02) recorded a slight decrease in fixation precision, which at T0 had reached ceiling levels. Furthermore, two participants (P02 and P03) showed an improvement in line tracing in the visual field test; in contrast, the performance of participant P01 in this test could not be evaluated at either baseline (T0) or post-intervention (T1). The difficulties he encountered could be attributable to the type of eyeglasses he used daily and wore during the entire experiment. In addition, regarding the calibration test, the performances of two participants (P02 and P03) had already reached a ceiling level at T0 and remained constant at T1. Instead, the other participant (P01) improved his calibration performance skills after training with eye-gaze-driven games.

Overall, these findings suggest that short-term training with eye-gaze-driven games may support improvements in fixation and visual exploration in individuals with spastic-dystonic cerebral palsy. These

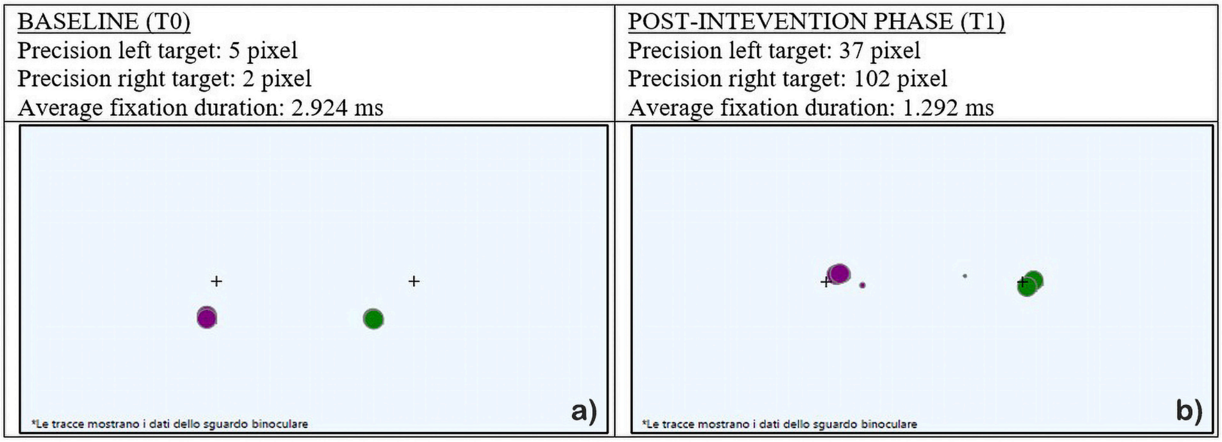

Fig. 6. Screenshot of participant P02's fixation test: a) at baseline (T0); b) at post-intervention phase (T1).

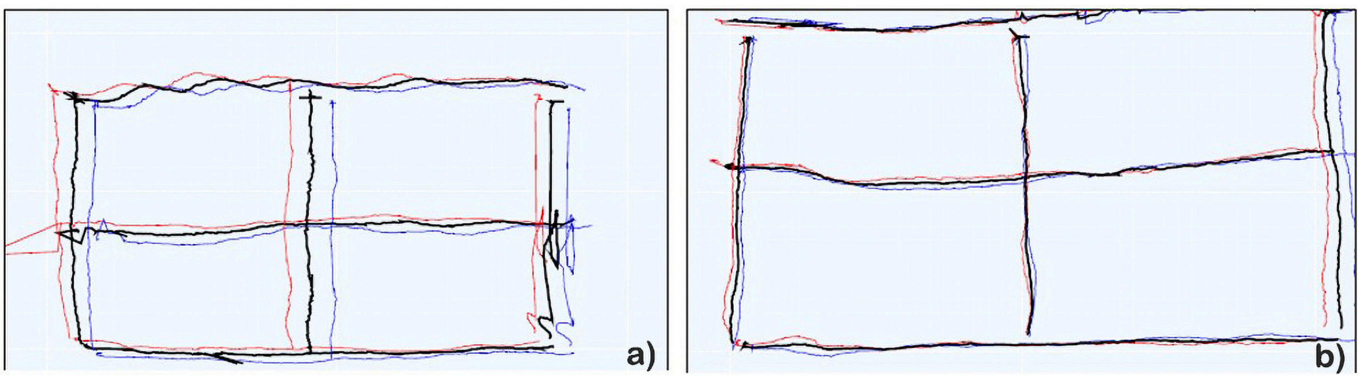

Fig. 7. Screenshot of participant P02's visual field test: a) at baseline (T0); b) at post-intervention phase (T1).

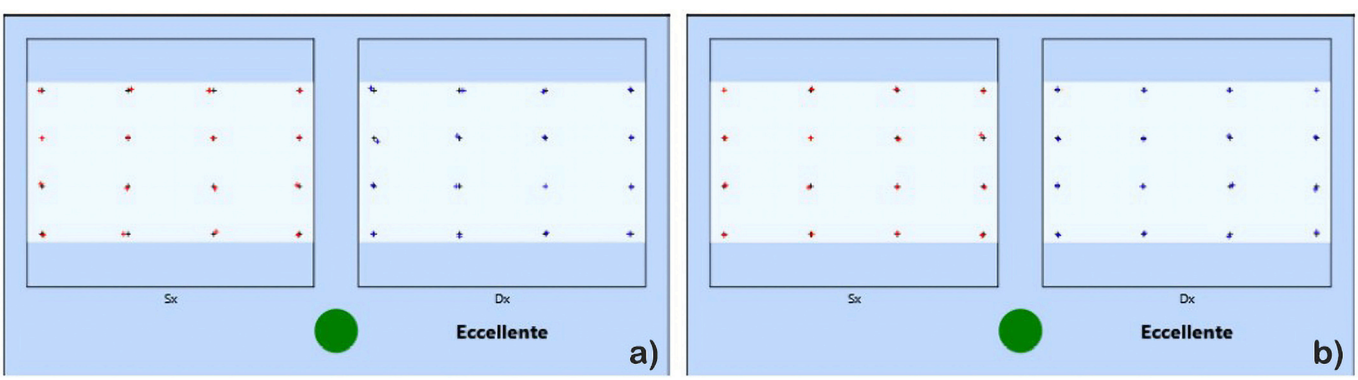

Fig. 8. Screenshot of participant P02's calibration test: a) at baseline (T0); b) at post-intervention phase (T1).

findings are consistent with previous studies conducted in paediatric populations, which reported improvements in oculomotor performance following eye-gaze-based interventions (Baranello et al., 2020; Bekteshi et al., 2020, 2022; Borgestig et al., 2016). Specifically, Bekteshi et al. (2020) demonstrated that operational competencies underlying eye-gaze performance, such as screen navigation and dwell function, can be improved through structured interventions lasting five weeks. The present study extends these findings to adults with heterogeneous functional profiles, suggesting that oculomotor benefits may also be observed following short-term training. Furthermore, with regard to execution speed (time on task), Borgestig et al. (2016) reported that improvements may occur after longer intervention periods. Given the short duration of the present study, this aspect could not be evaluated, highlighting the need for follow-up assessments in future research.

Moreover, at the end of the study, all participants completed a questionnaire assessing system usability. The overall mean SUS score corresponded to a "good" rating (grade B). This finding suggests that eye-gaze-driven games were well accepted by participants. This is especially relevant, given that user acceptance is a critical determinant of the successful adoption of assistive technologies in real-world settings.

However, this study warrants some critical reflections. First, the study recruited participants in a specific environment, and this allowed us to reach only three participants. This makes it impossible to generalize the results. Further studies with larger sample sizes are needed to verify the efficacy at a statistical level. Second, all participants had

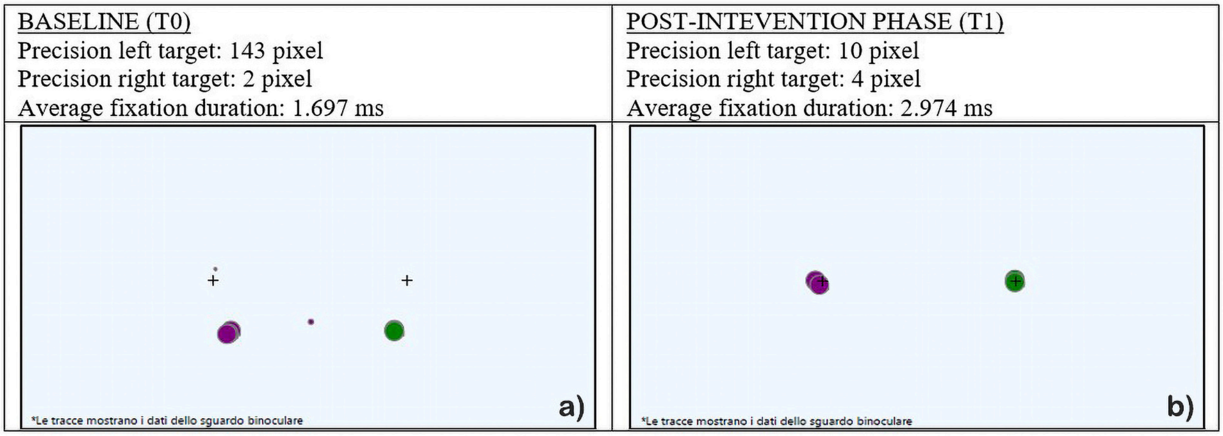

Fig. 9. Screenshot of participant P03's fixation test: a) at baseline (T0); b) at post-intervention phase (T1).

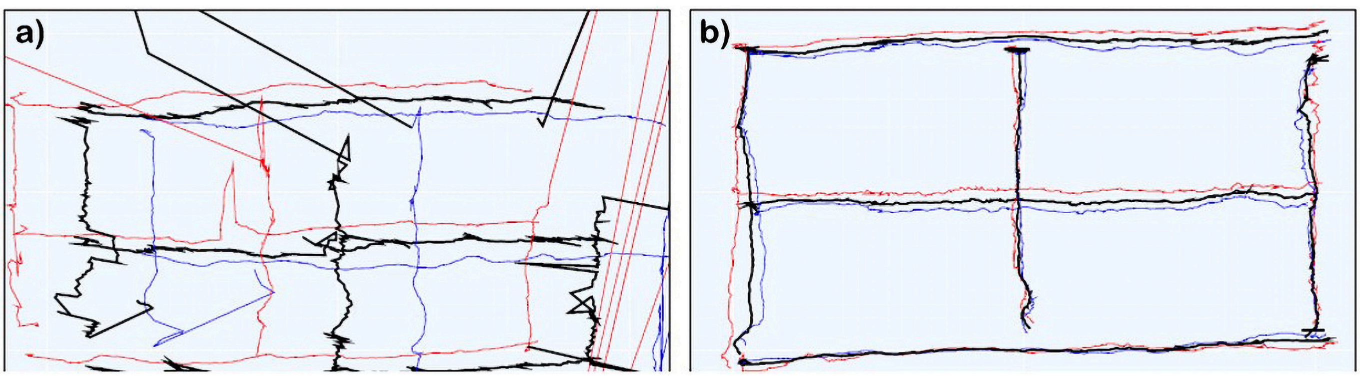

Fig. 10. Screenshot of participant P03's visual field test: a) at baseline (T0); b) at post-intervention phase (T1).

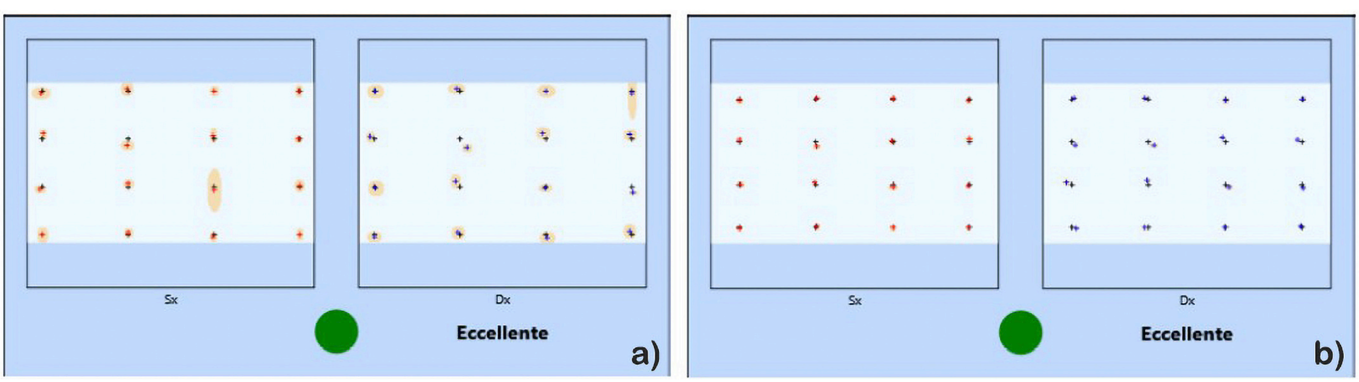

Fig. 11. Screenshot of participant P03's calibration test: a) at baseline (T0); b) at post-intervention phase (T1).

different functional profiles of spastic-dystonic cerebral palsy. It would be necessary to investigate whether different results are obtained with individuals with other types and functional profiles of cerebral palsy. Furthermore, this sample included only participants without intellectual deficits, who were all university graduates and were naïve to eye trackers. Consequently, in future studies, it could be interesting to investigate larger and more differentiated populations: children, people with different degrees of cognitive impairments, schooling and eye gaze's assistive technology experience.

Regarding the technical and methodological aspects, this study carried out five training sessions in a single week. Future studies should investigate whether different results are obtained by modifying the frequency, for example, increasing the number of sessions over a longer period. Furthermore, it should be considered whether the effects obtained persist over time; it would, therefore, be essential to provide a follow-up session. Finally, one participant experienced difficulties in managing the eye-tracking system, which may be associated with the use of corrective lenses. A more sophisticated eye-tracking device is strongly recommended for people with severe visual impairments. In particular, for tasks requiring high oculomotor precision, a higher sampling rate (e.g., ≥120 Hz) may be needed, as lower frequencies typical of entry-level commercial devices may not adequately capture fast saccadic movements (Andersson et al., 2009; Holmqvist et al., 2011).

5. Conclusions

To our knowledge, the present study is among the first to investigate the usability and potential impact of Look Lab software on oculomotor and visual-exploration skills in adults with cerebral palsy. The findings show that all participants were able to interact efficiently with the proposed activities using only their gaze, suggesting that the software may be accessible even to individuals with complex needs and may support improvements in eye gaze performance. Furthermore, this study reports positive feedback regarding the usability of gaze-based assistive technologies as a computer interface for individuals with cerebral palsy. This finding is particularly relevant, as user acceptance is a key factor in the real-world adoption of assistive technologies, and eye-gaze-based activities may represent a useful preparatory step for their effective use.

The absence of adverse effects, combined with participants' positive responses, further supports the possibility of using eye-gaze-based oculomotor interventions in rehabilitation. Such interventions may be beneficial for individuals with cerebral palsy by supporting the development of oculomotor skills necessary to interact with the environment through gaze. In this context, the ability to control an augmentative and alternative communication (AAC) interface or other computer-based systems through eye-tracking technologies may contribute to increased participation and inclusion of persons with disabilities in all domains of life (WHO, 2022), while also reducing dependence on caregivers.

Based on these findings, further research is needed to investigate the extent to which individuals with more severe disabilities may benefit from eye-gaze-based training, as well as its potential impact on eye-tracking use, communication skills, participation, and quality of life.

CRediT authorship contribution statement

Cristina Costantini: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Claudia Salatino:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Roberta Daini:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve the grammar, language, and readability of selected sections of the manuscript. After using this tool, the authors carefully reviewed and edited the content as needed and take full responsibility for the content of the publication.

Funding

Cristina Costantini was supported by a PhD scholarship from the Centre of Excellence of the Psychology Department of the Università degli Studi di Milano Bicocca.

Declaration of competing interest

Cristina Costantini reports financial support was provided by the Centre of Excellence of the Psychology Department of the Università degli Studi di Milano Bicocca. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to thank the three participants for their involvement in the study.

Data availability

All the data obtained in the study are reported in the manuscript

References

Abd Elmagid, D. S., & Magdy, H. (2021). Evaluation of risk factors for cerebral palsy. *The Egyptian Journal of Neurology, Psychiatry and Neurosurgery, 57*(1), Article 13. https://doi.org/10.1186/s41983-020-00265-1

Almutairi, A., Christy, J. B., & Vogtle, L. (2018). Vestibular and oculomotor function in children with cerebral palsy: A scoping review. *Seminars in Hearing, 39*(3), 288–304. https://doi.org/10.1055/s-0038-1666819

Andersson, R., Nyström, M., & Holmqvist, K. (2009). Sampling frequency and eye-tracking measures: How speed affects durations, latencies, and more. *Journal of Eye Movement Research, 3*(3), 1–12. https://doi.org/10.16910/jemr.3.3.6

Baranello, G., Signorini, S., Tinelli, F., Guzzetta, A., Pagliano, E., Rossi, A., … VFCS Study Group. (2020). Visual function classification system for children with cerebral palsy: Development and validation. *Developmental Medicine & Child Neurology, 62*(1), 104–110. https://doi.org/10.1111/dmcn.14270

Bax, M., Goldstein, M., Rosenbaum, P., Leviton, A., Paneth, N., Dan, B., Jacobsson, B., Damiano, D., & Executive Committee for the Definition of Cerebral Palsy. (2005). Proposed definition and classification of cerebral palsy, April 2005. *Developmental Medicine & Child Neurology, 47*(8), 571–576. https://doi.org/10.1017/s001216220500112x

Bekteshi, S., Karlsson, P., De Reyck, L., Vermeerbergen, K., Konings, M., Hellin, P., Aerts, J.-M., Hallez, H., Dan, B., & Monbaliu, E. (2022). Eye movements and stress during eye-tracking gaming performance in children with dyskinetic cerebral palsy. *Developmental Medicine & Child Neurology, 64*(11), 1402–1415. https://doi.org/10.1111/dmcn.15237

Bekteshi, S., Konings, M., Vanmechelen, I., Deklerck, J., Ortibus, E., Aerts, J.-M., Hallez, H., Karlsson, P., Dan, B., & Monbaliu, E. (2020). Eye gaze gaming intervention in children with dyskinetic cerebral palsy: A pilot study of task performance and its relation with dystonia and choreoathetosis. *Developmental Neurorehabilitation, 23*(8), 548–556. https://doi.org/10.1080/17518423.2020.1770890

Borgestig, M., Rytterström, P., & Hemmingsson, H. (2017). Gaze-based assistive technology used in daily life by children with severe physical impairments – Parents' experiences. *Developmental Neurorehabilitation, 20*(5), 301–308. https://doi.org/10.1080/17518423.2016.1211769

Borgestig, M., Sandqvist, J., Parsons, R., Falkmer, T., & Hemmingsson, H. (2016). Eye gaze performance for children with severe physical impairments using gaze-based assistive technology—A longitudinal study. *Assistive Technology, 28*(2), 93–102. https://doi.org/10.1080/10400435.2015.1092182

Bricolo, E., Salvi, C., Martelli, M., Arduino, L. S., & Daini, R. (2015). The effects of crowding on eye movement patterns in reading. *Acta Psychologica, 160*, 23–34. https://doi.org/10.1016/j.actpsy.2015.06.003

Brooke, J. (1996). SUS: A quick and dirty usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). Taylor & Francis.

Caligari, M., Godi, M., Guglielmetti, S., Franchignoni, F., & Nardone, A. (2013). Eye tracking communication devices in amyotrophic lateral sclerosis: Impact on disability and quality of life. *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration, 14*(7–8), 546–552. https://doi.org/10.3109/21678421.2013.803576

Caltenco, H. A., Breidegard, B., Jönsson, B., & Andreasen Struijk, L. N. S. (2012). Understanding computer users with tetraplegia: Survey of assistive technology users. *International Journal of Human-Computer Interaction, 28*(4), 258–268. https://doi.org/10.1080/10447318.2011.586305

Dan, B., Rosenbaum, P., Carr, L., Gough, M., Coughlan, J., & Nweke, N. (2026). Updated description of cerebral palsy. *Developmental Medicine & Child Neurology, 68*(4), 465–476. https://doi.org/10.1111/dmcn.70149

Dutton, G. N., Bowman, R., & Fazzi, E. (2014). Visual function. In B. Dan, M. Mayston, N. Paneth, & L. Rosenbloom (Eds.), *Cerebral palsy: Science and clinical practice*. Mac Keith Press.

Eliasson, A.-C., Krumlinde-Sundholm, L., Rösblad, B., Beckung, E., Arner, M., Öhrvall, A.-M., & Rosenbaum, P. (2006). The manual ability classification system (MACS) for children with cerebral palsy: Scale development and evidence of validity and reliability. *Developmental Medicine & Child Neurology, 48*(7), 549–554. https://doi.org/10.1017/S0012162206001162

Fazzi, E., Signorini, S. G., La Piana, R., Bertone, C., Misefari, W., Galli, J., … Bianchi, P. E. (2012). Neuro-ophthalmological disorders in cerebral palsy: Ophthalmological, oculomotor, and visual aspects. *Developmental Medicine & Child Neurology, 54*(8), 730–736. https://doi.org/10.1111/j.1469-8749.2012.04324.x

Hidecker, M. J. C., Paneth, N., Rosenbaum, P. L., Kent, R. D., Lillie, J., Eulenberg, J. B., … Taylor, K. (2011). Developing and validating the communication function classification system for individuals with cerebral palsy. *Developmental Medicine & Child Neurology, 53*(8), 704–710. https://doi.org/10.1111/j.1469-8749.2011.03996.x

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & Van de Weijer, J. (2011). *Eye tracking: A comprehensive guide to methods and measures*. Oxford University Press.

Hwang, C.-S., Weng, H.-H., Wang, L.-F., Tsai, C.-H., & Chang, H.-T. (2014). An eye-tracking assistive device improves the quality of life for ALS patients and reduces the caregivers' burden. *Journal of Motor Behavior, 46*(4), 233–238. https://doi.org/10.1080/00222895.2014.891970

Karlsson, P., Allsop, A., Dee-Price, B.-J., & Wallen, M. (2018). Eye-gaze control technology for children, adolescents and adults with cerebral palsy with significant physical disability: Findings from a systematic review. *Developmental Neurorehabilitation, 21*(8), 497–505. https://doi.org/10.1080/17518423.2017.1362057

Lampe, R., Turova, V., Blumenstein, T., & Alves-Pinto, A. (2014). Eye movement during reading in young adults with cerebral palsy measured with eye tracking. *Postgraduate Medicine, 126*(5), 146–158. https://doi.org/10.3810/pgm.2014.09.2809

Lewis, J. R. (2018). The system usability scale: Past, present, and future. *International Journal of Human-Computer Interaction, 34*(7), 577–590. https://doi.org/10.1080/10447318.2018.1455307

Palisano, R. J., Rosenbaum, P., Bartlett, D., & Livingston, M. H. (2008). Content validity of the expanded and revised gross motor function classification system. *Developmental Medicine & Child Neurology, 50*(10), 744–750. https://doi.org/10.1111/j.1469-8749.2008.03089.x

Pennington, L., Virella, D., Mjøen, T., da Graça Andrada, M., Murray, J., Colver, A., … de la Cruz, J. (2013). Development of the Viking speech scale to classify the speech of children with cerebral palsy. *Research in Developmental Disabilities, 34*(10), 3202–3210. https://doi.org/10.1016/j.ridd.2013.06.035

Rosenbaum, P., Paneth, N., Leviton, A., Goldstein, M., Bax, M., Damiano, D., Dan, B., & Jacobsson, B. (2007). A report: The definition and classification of cerebral palsy April 2006. *Developmental Medicine & Child Neurology, 49*(Suppl. 109), 8–14.

Sauro, J., & Lewis, J. R. (2016). *Quantifying the user experience: Practical statistics for user research*. Morgan Kaufmann.

Stavsky, M., Mor, O., Mastrolia, S. A., Greenbaum, S., Than, N. G., & Erez, O. (2017). Cerebral palsy—Trends in epidemiology and recent development in prenatal mechanisms of disease, treatment, and prevention. *Frontiers in Pediatrics, 5*, Article 21. https://doi.org/10.3389/fped.2017.00021

World Health Organization. (2022). *Global report on assistive technology*. World Health Organization. https://www.who.int/publications/i/item/9789240049451.