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Improving social-emotional abilities in children with profound intellectual and multiple disabilities through a person-centred eye-tracking-based training: A pilot study

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ABSTRACT

Individuals with profound intellectual and multiple disabilities (PIMD) are characterized by a combination of a profound intellectual disabilities and a profound motor disability frequently associated with a number of additional severe secondary disabilities or impairments. The aim of this pilot study was to evaluate the effects of an innovative person-centred training based on eye-tracking computerised serious games on the social-emotional abilities in these individuals with PIMD. Nine participants aged 7–18 years were followed over a period of 1 year. A pre-test (T1) – training – post-test (T2) design was used. During T1 and T2, visual attention and six social-emotional abilities (preferential attention to biological motion, social orienting, facial expression exploration, emotional faces discrimination, joint attention and socio-moral evaluations) were assessed using an eye-tracking-based experimental paradigm combining various visual preference tasks. During the training, each participant benefited from personalized one-to-one sessions tailored to their skills based on results of T1 and the observations of their practitioners. To implement person-centred training, the experimenter chose from a set of serious games to train these social-emotional abilities, those he felt were best suited to the participant's current state of heath and alertness, personal skills and specific needs. All participants improved their visual exploration between T1 and T2. In addition, they all made progress on at least one of the six social-emotional competencies. These results showed preliminary evidence that it is possible to increase some social-emotional abilities in these individuals with an adapted training, thus indicating that they also have unsuspected learning abilities.

1. Introduction

People with profound intellectual and multiple disabilities (PIMD) have two key defining characteristics: (a) profound intellectual disability and (b) profound motor disability. They also have a number of additional severe or profound secondary disabilities or impairments (Nakken & Vlaskamp, 2007). This is a heterogeneous group of particularly vulnerable individuals with significant limitations both in intellectual functioning and adaptive behaviour as expressed in conceptual, social, and practical adaptive skills (Schalock, Luckasson, & Tassé, 2021). In order to provide appropriate personalized assistance to people with such severe disabilities, support persons have to be sufficiently knowledgeable about individual needs, possibilities, or preferences (Vlaskamp, Hiemstra, & Wiersma, 2007). This is particularly difficult to do with the PIMD population since assessing persons with PIMD is a challenging process with multiple issues (Nakken & Vlaskamp, 2007; Vlaskamp, 2005). A recent overview identified the following six main methodological challenges in conducting research with individuals with PIMD: (a) participant demarcation (where the authors point out the different terminologies, the discussions about core elements of definition and the difficulties in operationalization and assessment of core elements), (b) participant recruitment (where the authors note the small sample sizes frequently due to low prevalence rates and lack of official PIMD diagnosis in young children, health problems causing dropout, limited numbers of recruitment channels and oversubscription, difficulties reaching and motivating families, underestimation of the

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learning potential of persons with PIMD), (c) data collection and instruments (where the authors point out the lack of specifically developed and evaluated instruments, difficulties in applying instruments for typically developing children, unsuitability of self-report, unclear validity of proxy report, problems with reliability and validity of behavioral observations, fluctuating alertness and attention levels of persons with PIMD, and disruptive factors in daily life situations), (d) data analysis (where the authors note that it is not always possible to take heterogeneity of the target group into account, and point out the use of non-parametric tests, the reliability and validity of qualitative data analysis, and the difficulties in finding an appropriate control group), (e) ethics (where the authors point out challenges in obtaining informed consent of persons with PIMD, in including the "voice" of persons with PIMD within the research process and in including significant others within the research process) and (f) theoretical models (where the authors note a lack of specific theoretical models and point out doubts about applicability of general theoretical models and the need for development of adapted/new specific theoretical models) (Maes et al., 2021).

In this context, the development of technologies such as eye-tracking may well help to facilitate the assessment of this population. Very few studies have already been carried out with this aim, for example, Chard, Roulin, and Bouvard (2014) used a visual habituation procedure to test the existence of the habituation/novelty reaction phenomenon in 15 adults with PIMD aged 35–54 years following the principles of a participant-controlled procedure. By conducting both qualitative and quantitative analyses of the observed behaviours (e.g., attention getting and holding processes) using a specially designed apparatus, they were able to show that the PIMD participants presented similar habituation profiles generally obtained in infant studies (Chard et al., 2014).

Recently, we demonstrated the relevance of the eye-tracking-based experimental paradigm we designed to assess six social-emotional abilities by using it with nine young individuals with PIMD (Cavadini, Courbois, & Gentaz, 2022). This paradigm combined various visual preference tasks adapted from pre-existing infant studies to test social-emotional abilities of great importance in later communicative development. Based on these first results, we aimed to use the eye-tracking technology to support social-emotional abilities in children and adolescents with PIMD through the implementation of person-centred training (Ratti et al., 2016). The person-centred approach tailors services around the individual rather than enforcing a "one-size-fits-all" structures as a system-centred approach does (Kaehne & Beyer, 2014). Implementing such training programmes would enable us to explore the learning potential abilities of these individuals by providing knowledge about the perceptual learning process in PIMD individuals. Perceptual learning generally refers to experience-induced changes in the way information is extracted. A large and growing set of research results indicates that such changes are not only possible but pervasive in human information processing (Kellman, 2002). This specific and implicit type of early learning occurs at different levels of information processing: on a full spectrum of tasks, from processing the most basic sensory discriminations to apprehending the most complex spatial and temporal patterns and relations, experience improves the pickup of information. These improvements affect almost all skilled behaviour, form important foundations of higher cognitive processes, interact with other kinds of learning in important ways, and furnish one of the most important components of high-level expertise (Kellman, 2002). Because of the nature of their disabilities, persons with PIMD are much more dependent on their perceptual system rather than their procedural (motor) system in the processing of external objects, which represents a major constraint with regard to learning in general. Despite their status as passive observers, PIMD individuals are regularly exposed to dynamic social and emotional stimuli in the course of daily activities (from practitioners, care staff and in their family). Consequently, they may have developed unsuspected cognitive and socio-emotional abilities through daily exposure to repeated perceptual events associated with subjective experience that cannot be assessed with existing evaluation methods and instruments but that eye-tracking-based training programmes could help to identify, thus contributing to better understanding the perceptual learning process in this population.

In the current study a pre-test – training – post-test design was used in order to investigate the effect of an innovative person-centred training using the eye-tracking technology to support social-emotional abilities in nine young PIMD individual (single cases) followed over a period of one year. Social-emotional abilities were assessed during test phases using the revised version of the eye-tracking-based experimental paradigm developed by Cavadini et al. (2022); Cavadini, Riviere, and Gentaz (2024) that combined various visual preference tasks adapted from pre-existing infant studies. Six social-emotional abilities of great importance in later communicative development were investigated, namely: preferential attention to biological motion, social orienting, facial expression exploration, emotional faces discrimination (anger vs. joy, joy vs. sadness and anger vs. sadness), joint attention and socio-moral evaluation.

Preferential attention to biological motion, which is one of the earliest perceptual abilities involved in the development of non-verbal communication (Pavlova, 2011), was assessed by the "PLM-Task". It consisted in simultaneously presenting two sets of nine dynamic light points arranged on a black background on either side of the screen, one depicting a human walking movement (biological motion), the other a random movement (non-biological motion) (Bidet-Ildei, Kitromilides, Orliaguet, Pavlova, & Gentaz, 2014; Johansson, 1973). Using similar paradigms, a large body of work has confirmed and demonstrated the existence of a spontaneous preference for biological over non-biological motion in humans but also in a wide range of animal species (Salva, Mayer, & Vallortigara, 2015). Moreover, this sensitivity appears very early in development: from the first days of life, human neonates preferentially direct their attention to this type of movement (Bardi, Regolin, & Simion, 2011; Bidet-Ildei et al., 2014; Simion, Regolin, & Bulf, 2008).

Social orienting was assessed using the "SO-Task" designed by Franchini et al. (2016) based on the previous work of Pierce, Conant, Hazin, Stoner, and Desmond (2011), in which children dancing solo next to moving geometric shapes were presented to participants in order to test whether they were able to discriminate socially salient stimuli from non-social scenes. Like preferential attention to biological motion, social orienting (i.e. the intrinsic ability to preferentially orient to our surrounding social environment (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998) appears very early in development: from birth, newborns show a particular sensitivity to socially salient stimuli (Farroni et al., 2013; Salva, Farroni, Regolin, Vallortigara, & Johnson, 2011). This includes being especially attracted to the people around them as well as to sounds, movements, and features of the human face (Farroni, Menon, & Johnson, 2006). This predisposition to orient preferentially to the social environment is of crucial importance the early in social-communicative development: by orienting to peers, infants prompt further interaction, creating rich learning opportunities through reciprocal social engagement (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012).

Pairs of emotional (angry, happy and sad) faces of female and male models from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998) were used to test face exploration in our participants, and more specifically whether they looked more at the eye area than at the mouth one. Numerous studies have demonstrated that both adults and children look at the eye area more than at any other facial feature (Hunnius, de Wit, Vrins, & von Hofsten, 2011; Palama, Malsert, & Gentaz, 2018). This preference has also been found in infants as young as three months of age (Dollion, Soussignan, Durand, Schaal, & Baudouin, 2015).The same stimuli were also used to test the ability to discriminate angry from happy faces, angry from sad faces and happy from sad faces. A very large body of work has studied the typical development of discrimination of emotional facial expressions during the early years. The literature review by Bayet, Pascalis, and Gentaz (2014) showed the existence of a sensitivity to changes in facial expression as well as an attraction to happy faces from the first days of life. However, the latter is not systematically reported at that age because newborns' discrimination abilities are limited by their low visual acuity and experience, and are modulated by several environmental factors (e.g., familiarity, contrast, intensity, etc.) (Tanaka & Gordon, 2011). This preference for smiling faces observed, under specific conditions, from birth, persists and is perfected during the first months of life. Between 3 and 6 months of age, babies are progressively able to differentiate joy from other emotional expressions: at 3 months, they discriminate the expression of joy from anger (frowning) and surprise; they then succeed in differentiating joy from sadness between 3 and 5 months, and from fear at 4 months, whereas they are able to discriminate between joy and neutral expressions as well as between joy and surprise from 5 months (Bayet et al., 2014). Finally, it is only from 6 to 7 months that babies are able to distinguish between expressions other than smiling (Grossmann, Striano, & Friederici, 2007).

Joint attention, defined as a co-created outcome of an interaction in which two individuals shared interest in the same object (Aubineau, Vandromme, & Le Driant, 2015), was assessed by both the "RJA-Task" and the "GD-Task". The RJA-Task tested whether the participant spent more time looking at an object pointed at or looked at with a surprised expression by an actress than at the same object neither pointed at nor looked at by her (Franchini et al., 2017). The GD-Task was designed to extend the RJA-Task by testing participants' ability to follow the dynamic gaze of a human face. Based on the previous work of N'Diaye, Sander, and Vuilleumier (2009), it consisted of presenting a neutral face (male or female taken from the Radboud Faces Database (Langner et al., 2010)) with a direct gaze gradually shifting to a surprised face with either leftward or rightward averted gaze. Joint attention is one of the earliest mechanisms by which a child can interact and learn (Mundy & Newell, 2007).

Finally, an adaptation of Hamlin, Wynn, and Bloom's (2007) "Climbing the Hill" paradigm, referred to here as the "SME-Task", was used to test participants' socio-moral evaluations through their visual preferences for pro- versus anti-social behaviour. Socio-moral ability can be defined as the capacity to evaluate others based on their prosocial or antisocial actions towards others (Hamlin et al., 2007). Although moral judgment (studied with verbal tasks) follows a staged development that extends from infancy to adolescence (Kohlberg, 1963), its foundations may be initiated very early. Indeed, it appears that infants are able to intuitively evaluate some social interactions long before the emergence of self-awareness, language, and theory of mind (Kuhlmeier, Dunfield, & O'Neill, 2014). By creating the Hill paradigm in which a puppet trying to climb a hill is either *helped* in its action by another character (i.e., the 'helper' with a prosocial behaviour) or *prevented* from reaching the top by another one pushing it down (i.e., the 'hinderer' with an antisocial behaviour), Hamlin et al. (2007) showed for the first time that infants were more attracted to prosocial actions (exhibiting reaching, grasping behaviours) as early as 6 months of age. By adding a visual preference procedure to this paradigm, they were even able to find that 10-month-old infants preferred to look at prosocial agents (Hamlin et al., 2007).

Between the two test phases, which took place a year apart, the training phase was conducted. This consisted of implementing an innovating person-centred training during which each participant regularly benefited from personalized one-to-one sessions (from 1 to 5 sessions per week of 15 to 30 min) tailored to their individual skills and needs. Through the use of computerised serious games designed especially for this research project, the study intended to provide new tools to support specific social emotional abilities in children and adolescents with PIMD and to promote broader cognitive skills using eye-tracking technology.

The objective of the present study was to assess the effects of implementing a person-centred training program. To this end, we compared gaze rates on visual stimuli recorded during the test phases conducted before and after the training phase (T1 vs. T2). Given the small sample size ($n = 9$), a common constraint in research involving individuals with PIMD due to recruitment challenges (Nakken & Vlaskamp, 2007), this study should be regarded as a pilot investigation. Framing it as such ensures that the findings are interpreted not as definitive conclusions, but rather as preliminary evidence that can inform future large-scale studies.

2. Methods

The current study (including experimental protocol and data collection) was conducted in accordance with ethical principles for research involving human subjects (World Medical Association Declaration of Helsinki) and was approved by the Ethics Committee of the University of Geneva. All parents gave their informed written consent for their child to take part and for the information to be published in an online open-access publication. All adults' participants gave their informed written consent to take part in the study. All names of participants reported in the current manuscript and in the database attached to it are pseudonyms. As a result, all information relating to the participants is anonymised in this manuscript and in the documents attached to it.

2.1. Participants

The present study included three distinct populations: an average 2-year-old control group (equivalent to the estimated developmental age of the PIMD population (Nakken & Vlaskamp, 2007)), an adult control group and nine young individuals with PIMD.

The first control group was composed of 56 TD children (28 girls and 28 boys), aged 12 to 35 months ($M = 22.31$, $SD = 6.88$). Every age between 12 and 35 months was fairly represented. They were all French-speaking Caucasian and lived in rural areas (< 3000 inhabitants; $n = 7$), villages (3000–10′000 inhabitants; $n = 11$), and urban areas (> 10′000 inhabitants; $n = 38$) in the surroundings of Geneva, Switzerland. All infants were full-term and healthy.

The second control group consisted of 101 TD adults (63 females and 38 males) aged 18 to 62 years ($M = 28.3$, $ET = 9.49$) recruited from the Geneva area in Switzerland. The majority ($n = 68$) were university students (bachelor's, master's or doctoral candidates), of whom 45 were students in psychology and 23 in another faculty. 27 individuals were salaried employees and 6 were unemployed.

Finally, this single-case study included nine children and adolescents (six girls and three boys, aged 7–18 years) with a diagnosis of PIMD. They all met the criteria set by the internationally accepted definition that the PIMD population consists of individuals with a profound intellectual disability in combination with a severe or profound motor disability (Nakken & Vlaskamp, 2007). Individual profiles of each of the nine participants are described below using pseudonyms in order to preserve the anonymity of the participants. Overall, none of them had functional verbal communication. They also all experienced severe motor limitations in their movement, not walking autonomously, and were thus totally dependent on support persons for all activities of daily life. Each was enrolled in the same Medical-Educational Institute (MEI) of the French Red Cross.

Participants' individual cognitive skill profile were established by a psychologist (who had known each of them for at least one year) using the Evaluation-Cognition-PIMD (ECP) scale (Poujol et al., 2021), which is presented in details later in the Methods section. Individual standardized scores (t-scores) on the ECP subscales are presented in Table 1.

Participant #1: Zoe was 7 years and 8 months old at the start of the current study. She was diagnosed with PIMD due to neonatal microcephaly caused by a mutation in the ASNS gene. This specific genetic anomaly responsible for Zoe's microcephaly was only identified in 2013 (Ruzzo et al., 2013): by 2018, no more than thirty cases had been described in the scientific literature (Schleinitz et al., 2018). Zoe presented axial hypotonia and peripheral hypertonia of the lower limbs with equinus feet. Despite this, she was able to crawl freely in her living

Table 1
Standardized scores (t-scores) on the ECP Scale of the nine PIMD participants at T1.

Participant	#1 Zoe*	#2 Nina*	#3 Suzan*	#4 Jane*	#5 Betty*	#6 Elise*	#7 Mike*	#8 John*	#9 Tim*
Age (years)	7	9	10	12	14	15	16	17	17
ECP subscales									
Sensory	61	51	41	38.5	50	40.5	63	44	52
Attentional	70	66	42	51	51.5	53	66.5	61.5	61.5
Memory	60	58.5	42.5	45.5	41	41	70	54	50
Communicative	60	51	35	48	53	43	65	62	51
Reasoning	47	52	40.5	50	52	52	64	62	54
Spatio-temporal	59.5	52	34	56.5	55	44	72	41	48.5
Learning	50	47	34.5	36	45	45	63	50	50
Social-emotional	62	62	44	51	54	49	69	52	59

Note. * pseudonyms were used to anonymise participants' first names.

space and was also capable of sitting up on her own. Zoe had no particular sensory deficits and showed relatively high attentional skills.

Participant #2: Nina was a girl aged 9 years and 2 months diagnosed with PIMD due to a Rett syndrome (RTT) resulting from a mutation in the MECP2 gene. Regarding the RTT cascade of clinical symptoms delineated in a staging system by Engerström (1990), Nina entered the Late Motor Deterioration stage (stage IV) since she ceased walking and became wheelchair-dependent. She presented a severe loss of muscle tone (hypotonia), postural stiffness, and varus feet. Nina also showed stereotyped hand movements, breathing irregularities (hyperventilation during wakefulness, forced expulsion of air and saliva), and a seizure disorder. She had no particular sensory deficits except for a strabismus and slight hyperopia corrected by wearing glasses. Nina showed remarkable eye contact and visual pointing behaviours, and appeared to have high attentional skills.

Participant #3: Suzan was a 10-year-old girl diagnosed with PIMD due to a hypoxic-ischemic encephalopathy (HIE) resulting from a sudden infant death from which she was rescued at the age of 4 months. She presented spastic tetraparesia associated with significant hypotonia. Her secondary deficits included severe epilepsy, right hip dislocation, and sleeping disorders. Suzan tended to be quite floppy, showing minimal reactions to sights or sounds, and exhibiting fluctuating abilities. She had no particular sensory deficits other than the fact that she was often hypothermic. She had relatively low scores on almost all ECP subscales (particularly with regard to spatial-temporal skills and learning; conversely, her best score was for socio-emotional skills).

Participant #4: Jane was a 12-year-old girl diagnosed with PIMD due to Nicolaides-Baraitser syndrome caused by a heterozygous missense mutation in the SMARCA2 gene combined with a Chiari type 1 malformation. Despite ankle dorsiflexion, equinovarus feet, and rheumatological disorders, Jane was able to walk (crouching gait) short distances with the assistance of a support person to move freely around a room or to reach a goal. She obtained a relatively high score on the ECP subscale measuring spatial-temporal skills. On the other hand, her scores on learning and sensory skills were low, although she had no particular sensory deficits.

Participant #5: Betty was a 14-and-a-half-year-old girl diagnosed with PIMD due to infantile epileptic encephalopathy with hypsarrhythmia identified as idiopathic West syndrome (also known as infantile spasms). Betty's severe generalized tonic-clonic seizures (consisting of series of sudden involuntary muscle contractions in flexion) first appeared when she was 5 months old, although she had no genetic abnormalities or any brain damage. She presented axial hypotonia (mainly in the extensor muscles of the neck and spine, leading to a global kyphosis of the latter) and peripheral hypertonia (stiffness of the lower limbs). She had no particular sensory deficits but exhibited significant, challenging, self-aggressive behaviours and stereotyped movements of the upper limbs. Betty showed very limited communicative and attentional skills resulting in difficulties in maintaining eye contact and decreased responses to sound stimuli.

Participant #6: Elise was a teenage girl aged 15 years and 5 months diagnosed with PIMD due to early infantile epileptic encephalopathy (EIEE) with suppression-burst, also known as Ohtahara syndrome, caused by a heterozygous missense mutation in the STXBP1 gene. She presented hypertonia, spasticity, dorso-lumbar scoliosis, hip subluxation as well as severe and irreducible foot deformities: equinovalgus left foot and varus right foot. As associated secondary disorders, Elise had epilepsy (treated and stabilized for one year), early onset of puberty (from the age of 8 years), and chronic constipation. She had no particular sensory deficits except for reflexive startle movements to noises (accentuated by fatigue). She obtained high scores on the ECP subscales measuring attentional and socio-emotional skills. However, her scores on memory and sensory skills were quite low.

Participant #7: Mike was a 16-year-old teenage boy diagnosed with PIMD due to neonatal epileptic encephalopathy (NEE) caused by a heterozygous pathogenic variant in the KCNQ2 gene. He presented axial hypotonia and spastic quadriplegia yet he was able to walk a few meters with support (crouch gait), make the transition from sitting to standing, and stand for a while, especially when changing posture (e.g., from his wheelchair to other support devices), during care or dressing. Mike exhibited several stereotyped behaviours but no particular sensory deficits. Consistently, he scored rather high on almost all ECP subscales, particularly with regard to spatial-temporal skills and memory. In addition, he had great eye contact and very precise visual pointing behaviours. Combined with his cognitive performance, Mike's accurate ocular movements enabled him to start learning to use an alternative communication system to express his choices by selecting corresponding pictograms.

Participant #8: John was a male adolescent of 17 years and 6 months diagnosed with PIMD due to an Aromatic L-amino acid decarboxylase (AADC) deficiency, consisting in a rare autosomal recessive neurometabolic disorder. John presented severe hypotonia, spasticity and muscle stiffness. He had no particular sensory deficits but exhibited many uncontrolled movements (oculogyric crisis, dystonia, and hypokinesia), and autonomic symptoms such as impaired sweating, nasal congestion, drooling, hypotension, and severe gastroesophageal reflux. John had relatively high cognitive skills, especially in communication, memory (visual and auditory) and in reasoning. Through the regular use of computer-based educational programmes over the past two years, John's understanding of causal relationships has improved significantly. He also had good social-emotional skills. John was very expressive (showing his joy, happiness and interest but also his disagreement and opposition through different reactions), joking and receptive to humour and irony.

Participant #9: Tim was a 17-year-11-month-old male adolescent diagnosed with PIMD due to Ring chromosome 14 syndrome, characterized by early onset refractory epilepsy, intellectual disability, autism spectrum disorder (whereby Tim was first diagnosed with ASD at the age of 4), and a number of diverse health problems such as dorso-lumbar scoliosis, flexion contractures, early arthritis, recurrent pneumonia and respiratory tract infections. Nevertheless, Tim did not have any additional sensory deficits and showed fairly good attentional and social-emotional skills.

2.2. Test phases

2.2.1. Apparatus

Eye-tracking data were collected during the test phases using the screen-based Tobii Pro X3–120 binocular corneal-reflection eye-tracker bar (Tobii Technology AB) which records at a gaze sampling frequency of 120 Hz and has a temporal resolution of 8.3 milliseconds (ms). Two distinct test phases were conducted: T1 occurred between November and December 2021 and T2 occurred one year later (after the training phase) between November and December 2022. At each of these two measurement times, the participants completed either six (n = 3) or seven (n = 6) individual sessions, depending on their availability (those with the most medical care scheduled completed only six, while those with more free time were able to complete seven sessions). They attended one to two sessions a week over a period of around two months. These sessions were never scheduled in advance: the experimenter went to the MEI one or two days a week and conducted sessions with the participants as soon as one of them was available and suitable (in terms of state of health and alertness) to perform one. Participants were tested in a sound-attenuated and dimly illuminated room and were seated ~65 cm from a 22-in. computer monitor with a resolution of 1920 × 1080 px (visual angle $\alpha \simeq 31.5^\circ$).

2.2.2. Stimuli

A session consisted of the following elements: (a) a 30-s opening cartoon (to focus participants' attention), (b) a 5-point (for the PIMD participants and the TD children) or a 9-point (for the TD adults) calibration procedure (i.e., completed when five or nine points were successfully calibrated and repeated for the missing ones) in which an expanding-contracting white circle appeared on a black background in every position of a grid extracting five or nine points from the four corners of the screen (a satisfactory calibration was achieved with $<2^\circ$ of deviation on the X and Y axes), (c) the implementation of our experimental eye-tracking-based paradigm, and (d) a brief final animation (a puppet thanking the participant and saying goodbye) for a total duration of about 7–8 min. Although we had previously demonstrated the feasibility of our experimental paradigm and its suitability for evaluating our nine participants (Cavadini et al., 2022), in the present study we used a revised version of this paradigm (Cavadini et al., 2024) that took into account the limitations highlighted by our previous study. This paradigm consisted of the successive presentation (in random order) of the following different tasks inspired by pre-existing work in the field of infancy research.

The "Point-Light Motion (PLM)-Task" of our paradigm used the stimuli created by Bidet-Ildei et al. (2014) to measure our participants' ability to discriminate biological motion from non-biological motion. Biological motion was represented by dynamic points of light depicting the movement of a human walker (nine points: the head, one shoulder, one elbow, one wrist, one hip, both knees and both ankles) over a second set of nine randomly moving points (non-biological motion). The amount of movement per point was equivalent between conditions (Bidet-Ildei et al., 2014). This task consisted of four 10-s trials separated from each other by a dynamic fixation cross paired with a stimulating sound presented in the centre of the screen for 1.5 s. The lateral position of the two motion types was randomly alternated between each trial. They were delineated by two 850 × 1080-px AOIs. In addition, among the four trials, in two of them the dots were moving from the centre of the screen to the sides and from the sides of the screen to the centre in the other two trials.

The "Social Orienting (SO)-Task" of our paradigm used the stimuli created by Franchini et al. (2016) based on the previous work of Pierce et al. (2011), to measure the ability to discriminate socially salient visual scenes from non-social scenes in our participants. It included eight 5-s trials (for a total duration of approximately 50.5 s including the additional time generated by the presentation of the fixation cross between each trial). The stimuli pairs thus presented consisted of dynamic social images (sequences showing a young boy or girl moving and dancing solo) beside dynamic geometric images (moving geometrical shapes similar to classic abstract screen savers). They were delineated by two 850 × 1080-px AOIs. The structure of the paired-comparison stimulus display was controlled by the authors who initially designed this task: the stimuli were equal in visual salience independently of social/non-social conditions, the stimulus brightness was also equivalent between conditions as well as was the area of moving elements (Franchini et al., 2016).

The male and female emotional (angry, happy and sad) faces used to test both the *Facial Expression Exploration* and *Emotional Faces Discrimination* abilities of our participants came from the "The Karolinska Directed Emotional Faces – KDEF" (Lundqvist et al., 1998). Since two competencies were studied using emotional faces (Facial expression exploration and Emotional faces discrimination), we decided to dedicate two experimental 'blocks' (each composed of three randomly ordered 8-s trials) to these stimuli: one consisting of three pairs of emotional expressions (*angry* vs. *happy* faces, *angry* vs. *sad* faces, and *happy* vs. *sad* faces) of a female model (respectively references F22, F14, and F23) and the other of a male model (respectively references M17, M05, and M16). This selection was made from the 20 best anger, joy and sadness pictures established in the KDEF validation article (Goeleven, De Raedt, Leyman, & Verschuere, 2008). Stimuli were presented in color on a medium grey background (RGB 100, 100, 100) to increase ecological validity (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012). In each pair of stimuli, the model's teeth were either visible on both faces presented simultaneously or not visible on either face, since teeth have been shown to be a particularly salient facial feature influencing emotion discrimination (Caron, Caron, & Myers, 1985). The hairline, another facial feature known to affect the visual exploration of faces (Turati, Macchi Cassia, Simion, & Leo, 2006) was cropped using GIMP software (version 2.10). Different AOIs were drawn as the two abilities were actually measured by comparing the time spent looking at different locations: (a) time on the *eye area* (composed of two AOIs of 215 × 215 px each, spaced 80 px apart) vs. on the *mouth area* (consisting of an AOI of 430 × 215 px, equivalent to the size of the eye area) for visual scanning of facial features, and (b) time on each paired emotion (defined by two 740 × 980-px AOIs, symmetrically located at a distance of 110 px from the screen centre) for emotion discrimination.

The "Response to Joint Attention (RJA)-Task" of our paradigm used an adaptation of the stimuli created by Franchini et al. (2017) to test participants' ability to follow the direction of others' gaze to share a common point of reference. The task consisted of four 14-s videos in which an actress was standing in front of a table with two identical objects (of different natures, shapes, and colours in each video) on it. In this initial position, the actress was looking directly at the camera. After 2 s, the objects started to move, she then suddenly focused her attention on one of them, either by showing an expression of intense surprise for 12 s or by pointing at it for the same duration. From a total of 8 available video sequences, the software randomly selected two videos from the 'surprise' condition and two from the 'pointing' condition. The objects' location was defined by two 860 × 500-px AOIs (symmetrically located at a distance of 50 px from the centre of the screen length) whereas the actress' head was delimited by an additional AOI of the same size. This third area was of great importance because it had to be gazed for at least 500 milliseconds (i.e., minimum fixation duration threshold for visual processing of dynamic scene information in free-viewing condition according to Glöckner and Herbold (2011) for a trial to be validated and included in the analyses. All AOIs were only activated when the actress started to be surprised by one of the objects (i.e., 2 s after the video started) for a duration of 12 s.

The "Gaze Direction (GD)-Task" we designed was intended to extend the previous RJA-Task by focusing on our participants' ability to follow the dynamic gaze of a human face. Inspired by the work of N'Diaye et al. (2009), this task consisted of presenting a neutral face (male or female) with a direct gaze gradually shifting to a surprised face with either leftward or rightward averted gaze (each side of the screen was delineated by a 850 × 1080-px AOI). The GD-Task consisted of four 8-s trials during which two female faces (one gazing to the right and the other to the left) and two male faces (each also gazing to a different side of the screen) taken from the Radboud Faces Database (Langner et al., 2010) (ref. F14, F19, M23 and M24) that were presented in random order.

The "Socio-Moral Evaluation (SME)-Task" of our paradigm was an adaptation of the "Climbing the hill" paradigm (Hamlin et al., 2007), in which a 'climber' puppet (a red, circular wooden character with large plastic 'googly' eyes) tried but failed to climb a steep hill, and was randomly either bumped up the hill by the 'helper' (prosocial behaviour) or bumped down the hill by the 'hinderer' (antisocial behaviour). The helper/hinderer roles were counterbalanced over two contrasting stimulus shapes: a blue square and a yellow triangle with googly eyes. Each of these 'climbing scenes' lasted 14 s. This first part of the task was followed by a final visual preference scene (consisting of two 12-s trials), in which both the helper and the hinderer puppets were simultaneously presented side by side on the entire screen surface (delineated by two 850 × 1080-px AOIs). Consequently, our SME-Task differed from the others by its structure (the visual preference scene was only a part of the task, occurring only after the presentation of the first two climbing scenes). In addition, participants' socio-moral evaluation ability was also measured by comparing the time spent gazing at each climbing scene to determine whether one of the two observed behaviours (pro- vs. antisocial) attracted more visual attention.

2.2.3. Procedure

The eye-tracking data were collected using the screen-based experimental paradigm used during the test phases. This paradigm was composed of the six tasks described above, all using a classic fixed-trial visual preference procedure. This experimental method was first developed by Fantz (1963) to study the perceptual abilities of infants. Combined here with an eye-tracking device, it consists in simultaneously presenting a person with two visual stimuli which differ from each other on one property (stimuli 'A' and 'B') placed side by side, on either side of a presentation screen equipped with the eye-tracker and then comparing the time spent looking at the stimulus located on the left side of the screen versus at the one on the right side. Usually, the visual scene formed by the pair of A-B stimuli is presented repeatedly (i.e., trials) by alternating their respective positions on the screen across the different trials in order to laterally counterbalance the stimuli's locations and thus limiting side bias. When a person spends, on average, more time looking at one of the two stimuli, it can be said that he or she has perceived a difference between the two stimuli presented. However, if they are equally gazed, it is not possible to draw any conclusions: in this case, we cannot know whether the person perceived that they differed from each other or not.

Given that we decided to use a visual preference procedure involving the simultaneous presentation of two side-by-side stimuli, each task had a minimum of two trials in order to counterbalance the lateral location of the two paired stimuli. Each block and all trials were separated by the presentation of a dynamic fixation cross paired with a stimulating sound in the centre of the screen. Its duration was fixed at 1.5 s between trials, whereas between blocks it had to be gazed for at least 300 ms for the next one to be triggered. This choice was based on the fact that shorter-duration fixations than the 300 ms threshold are commonly considered involuntary (Bylinskii, Borkin, Kim, Pfister, & Oliva, 2017; Negi & Mitra, 2020). The activation area drawn around it sized 400 × 400 px. The order of presentation of the seven blocks as well as that of their respective trials was random.

Since we used a basic 5-point calibration procedure and, in addition, participants' gaze was repeatedly redirected to the centre of the screen, we decided not to record data on the area at the intersection of the two stimuli over the entire height of the screen. Therefore, when the two paired stimuli extended across the entire screen surface (as in PLM-, SO-, GD- and SME-Tasks), their respective positions were defined by two areas of 850 × 1080 px that were activated only after 300 ms of visual scene presentation. There was thus a central 220 × 1080-px strip in the middle of the screen which was not covered by any AOIs and whose width was defined on the basis of the distance separating the pairs of emotional faces.

2.3. The Evaluation-Cognition-PIMD (ECP) scale

The Evaluation-Cognition-PIMD (ECP) scale that was used in the current study is the revised version of the Francophone assessment tool called the "P2CJP–Profil de Compétences Cognitives du Jeune Polyhandicapé" (Pereira Da Costa & Scelles, 2012), which was designed for children up to 14 years of age. Validated in 2021, the ECP scale has now been extended to adults. This observation-based instrument, was developed by a group of French academics and clinical psychologists to assess a wide range of competencies and thus establish valid individual profiles of the following eight cognitive skills explored through 62 items: sensory skills, attention, memory, communication, reasoning, spatial-temporal skills, learning and social-emotional skills (Poujol et al., 2021). In the current study, the ECP scale was completed for each participant by a psychologist before the training phase (at T1) and after the training phase (at T2). An additional measurement time took place one year before the start of the study (T0). Table 2 compares the individual standardized ECP subscales scores (*t*-scores) at T0, T1 and T2.

2.4. Innovative person-centred training phase

2.4.1. Apparatus

In the current study the eye-tracking technology also served as a device to replace the computer mouse and keyboard, so that participants were able to control the computer with their eyes during the training phase. To this end, the Tobii Eye Tracker 4C (sampling rate: 90 Hz**)** was used during the training phase as a PC gaming eye-tracker peripheral. The *Tobii Eye Tracking Core* software (open source software that can be downloaded from: https://gaming.tobii.com/getstarted/) was used to set up and calibrate this device. Although the Tobii Eye Tracker 4C is fully compatible with the Windows 10 operating system and latest versions, we preferred to use the control bar provided by the *Mill Mouse* free access software version 7.13 (https://millmouse.wordpress.com/), which is customizable and more intuitive than the default Windows bar. Generally, the eye-tracking device was used solely as a game controller. However, in the case of some specific serious games that we used, eye-tracking data was also recorded, such as scan paths and heat maps indicating the eye movements and areas of the screen that most attracted the user's attention. One of these games also measured the number of fixations and the time spent looking at specific characters during use.

2.4.2. Software and serious games used

The person-centred training implemented in the current study aimed to encourage the user to explore the whole screen and improve visual attention, to support specific social emotional abilities and to promote broader cognitive skills using eye-tracking technology. To this end, we used a wide range of serious games.

Firstly, we selected and customized several games from the *Gazeplay* open access software (https://gazeplay.github.io/GazePlay/). These were aimed notably at promoting screen exploration as well as supporting social orientating and enhancing emotional skills (in particular emotion identification and comprehension of emotions). Table 3 describes the different games used, detailing how we customized them, the competencies targeted and the data collected.

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Table 2
Standardized scores (t-scores) on the Evaluation-Cognition-PIMD (ECP) Scale of the nine PIMD participants at T0 (i.e. before the training phase), at T1 (T0 + 1 year) and after the training phase at T2 (T1 + 1 year).

	#1 Zoe, 7 yo			#2 Nina, 9 yo			#3 Suzan, 10 yo			#4 Jane, 12 yo			#5 Betty, 14 yo			#6 Elise,15 yo			#7 Mike, 16 yo			#8 John, 17 yo			#9 Tim, 17 yo		
ECP subscales	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
Sensory	56	61	66	46	51	53,5	36	41	43,5	41	38,5	43,5	44	50	54	40,5	40,5	44	61	63	66,5	42	44	50	50	52	54
Attentional	68	70	76	61	66	68	40	42	46	53	51	57	50	51,5	55	48	53	55	68	66,5	73	60	61,5	65	63	61,5	68
Memory	58,5	60	63	57	58,5	61,5	39,5	42,5	45,5	44	45,5	50	48	41	50	46	41	48	70	70	70	56	54	62	54	50	58
Communicative	57	60	64	52	51	54	36	35	40	47	48	53	51	53	57	44	43	46	62	65	65	60	62	64,5	50	51	54
Reasoning	44	47	52	50	52	56,5	37	40,5	43	47	50	53,5	51	52	58	51	52	55	59	64	68	57	62	66	54	54	56
Spatio-temporal	58	59,5	62,5	46	52	55	32,5	34	36,5	58	56,5	61	52	55	62	41	44	51	69	72	74	40	41	44	47	48,5	52
Learning	48,5	50	53	50	47	53	36	34,5	39	33	36	42	46,5	45	53	45	45	49	58	63	67	48	50	55	51,5	50	53
Social-emotional	60	62	67	60	62	67	43	44	47	50	51	56	52	54	60,5	50	49	55	67	69	74	54	52	60	60	59	63

Note. By adding up the gains in individual scores on the eight ECP subscales between T0 and T1 and then between T1 and T2, it is clear that the scores of each participant increased significantly more between T1 and T2 (i.e. after receiving training) than between T0 and T1: Zoé's scores increased by 19.5 between T0 and T1 and by 34 between T1 and T2, Nina's scores increased by 17.5 between T0 and T1 and by 29 between T1 and T2, Suzan's scores increased by 13. 5 between T0 and T1 and by 27 between T1 and T2, Jane's scores increased by 3.5 between T0 and T1 and by 39.5 between T1 and T2, Betty's scores increased by 7 between T0 and T1 and by 46 between T1 and T2, Elise's scores increased by 2 between T0 and T1 and by 35. 5 between T1 and T2, Mike's scores increased by 18.5 between T0 and T1 and by 25 between T1 and T2, John's scores increased by 9.5 between T0 and T1 and by 40 between T1 and T2, finally, Tim's scores increased by −3.5 between T0 and T1 and by 32 between T1 and T2.

(Sciences in Learning and Teaching Technologies) department at the University of Geneva also led to the design of an original software programme called *Attention eye* (open-access download available at: https://tecfaetu.unige.ch/etu-maltt/aegir/elhamde0/vip/attention_eye/exe_attention_eye.zip) aimed at promoting (1) preferential attention for biological motion, (2) emotion recognition, (3) joint attention, and (4) prosocial behaviour through four different serious games (see Table 4 for a detailed description of the various games provided by this software).

Finally, a freelance user interface (UI) designer has developed software that focuses exclusively on socio-moral evaluations, based on the Hill paradigm (free download link: https://drive.switch.ch/index.php/s/CmfOT51uI2PZYy1). Similar to the initial situation of the Hill paradigm, this serious game opens with a scene in which a character (represented by a circle with two eyes and a horizontal bar for a mouth) tries again and again to climb a hill. At this point, the user can decide to grab either a second character at the top of the hill or a third character at the bottom of the hill by looking at one of them for at least 1.5 s. By grabbing the character at the top of the hill, the user can activate the latter by then directing his/her gaze towards the bottom of the hill: this triggers anti-social behaviour towards the climber, who is pushed down with a groan of "Noooo" and whose neutral expression becomes sad. Conversely, by grabbing the character at the bottom of the hill and directing his/her gaze towards the top of the hill, the user activates the pro-social behaviour, helping the climber who utters the sound "Yay" and whose neutral expression becomes cheerful. As soon as one of the two possible actions is performed, the game automatically restarts the initial situation by randomly reversing the direction of the hill's layout. The time spent looking at each character and the number of times each of the two actions was performed were automatically recorded.

Particular care was taken to ensure that different stimuli were used during the training phase than in the test phases (e.g. the emotional faces used to customise the Gazeplay software games were taken from a different image bank and all the content of the Attention Eye and Climbing the hill software was original and innovative).

2.4.3. Procedure

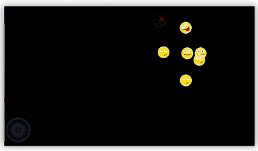
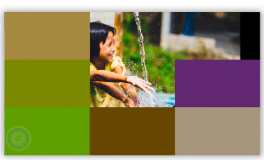
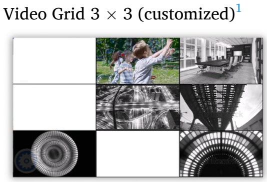
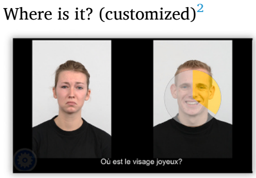
The training phase began in January 2022 and lasted one year. During this period, each of the nine participants regularly benefited from personalized one-to-one sessions (from 1 to 5 sessions per week of 15 to 30 min, for a total of 40 to 100 individual sessions per participant) tailored to their individual skills and needs. Indeed, in order to implement a person-centred training, the experimenter (who could be either a researcher or an educator from the MEI) had a large range of serious games at his/her disposal, from which he/she chose those he/she felt were best suited to the participant's current state of heath and alertness, personal skills and specific needs. In contrast to the test phases (where the experimenter was out of the participant's field of vision and remained silent during the sessions), the experimenter was actively involved in the training sessions: he or she stood in front of the screen next to the participant and encouraged the latter to perform the various serious games proposed (by means of sounds, facial expressions, applause, etc.). According to the person-centred approach, the composition of the training sessions varied greatly between participants and also within individuals over time. Nevertheless, most of the time, two to four games were used per session for around 3 to 5 min each (with the exception of the Bubbles and Divisor games, which were used as a warm-up and generally lasted less than a minute).

2.5. Data analysis

2.5.1. Data processing

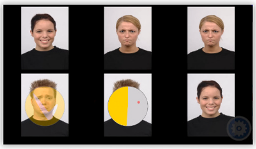
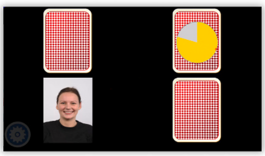
Analysis was based on raw eye samples in order to get the maximal data available from eye-tracker during the short trials of the test phases. Eye-tracking data was extracted using Tobii Pro Lab (version 1.162) computer software, which obtained metrics on *total visit duration* (i.e.,

Table 3
Detailed presentation of the different serious games from the *Gazeplay* software (https://gazeplay.github.io/GazePlay/) used during the training phase.

	Description	Customisation	Targeted skill(s) & measures
Bubbles (customized) 	Bubbles containing portraits slowly rise to the surface and explode when the player looks at them.	Default portraits have been replaced by emoticon packs	• Warm Up - Nothing in particular: the game was used as an indicator of the user's availability and alertness. • Screen exploration - Playing time (until user loses interest) - Gazeplot
Divisor (customized) 	Several targets move randomly on the screen. By looking at them, the user can split them into two smaller targets until there are no more.	Default targets have been replaced by emoticon packs	• Warm Up - Nothing in particular: the game was used as an indicator of the user's availability and alertness. • Screen exploration - Playing time (until user loses interest) - Gazeplot
Scratch Cards (customized)[1] 	A large image is hidden in a scratch card. The player scratches the card with their eyes. When a large portion of the card has been scratched, the image is displayed and the reward* offered.	Default image have been replaced by a wide selection of social images (i.e. showing at least two humans sharing their attention on a common interest or activity) taken from the open library dataset "Unsplash".	• Screen exploration • Social orienting - Number of images explored alone/with help (if necessary) - Time to explore each image alone/with help (if necessary) - Total playing time
Blocks (customized)[1] 	A large picture is hidden by a configurable number of coloured blocks that the player must look at to make them disappear. When all the blocks have disappeared, the reward* is offered.	Default pictures have been replaced by a wide selection of social images (the same as for the *Scratch Cards* game) taken from the open library dataset "Unsplash".	• Screen exploration • Social orienting - Difficulty level (number of blocks) - Number of images explored alone/with help (if necessary) - Time to explore each image alone/with help (if necessary) - Total playing time
Video Grid 2 × 2 (customized)[1] 	The user can play multiple videos as he/she watch them to read them.	The grid was made up of 4 videos: 1 social video (e.g. two children interacting) and 3 non-social videos (e.g. a rolling football, an unzoomed office and a motorway).	• Social orienting - Number of grids presented - Duration of presentation of each grid - Time spent until activation of the social video - Number of activations of each video - Total playing time
Video Grid 3 × 3 (customized)[1] 	The user can play multiple videos as he/she watch them to read them.	The grid was made up of 9 videos: 1 social video (e.g. children interacting), 4 non-social videos and 3 blank videos (white spaces on the grid).	• Social orienting - Number of grids presented - Duration of presentation of each grid - Time spent until activation of the social video - Number of activations of each video - Number of fixations on each video type (social, non-social, empty) per grid presented - Total playing time
Where is it? (customized)[2] 	The player must look at the image that corresponds to what was indicated at the beginning of the game read out loud by the experimenter during the game. When the emotion corresponding to the instruction is gazed at, the reward* is offered.	Female and male emotional faces (joy, sadness, anger) taken from the Langner et al. (2010)'s *Radboud Faces Database* (RaFD) were used (Langner et al., 2010).	• Emotion discrimination - Number of rounds played - Pairs of emotions tested in each round - Success/failure of each round - Total playing time
Open Memory (customized)[2]			

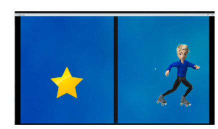
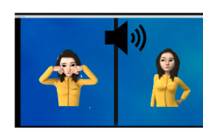
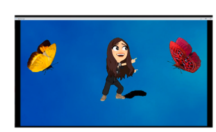
(continued on next page)

Table 3 (*continued*)

	Description	Customisation	Targeted skill(s) & measures
	The player must match cards that have the same picture and that are not face down by looking at them. When all the pairs have been matched the reward* is offered.	Default pictures have been replaced by female and male emotional faces (joy, sadness, anger) taken from the RaFD (Langner et al., 2010). Additional emotions could be added according to the user's discrimination abilities.	• Emotion discrimination - Difficulty level (number of pairs presented) - Number of rounds played - Time to match the different pairs in each round (time for each pair and total time) - Number of failures (mismatches) - Total playing time
Memory (customized)[2] 	The player must match cards that have the same picture by looking at them. When all the pairs have been matched the reward* is offered.	Default pictures replaced have been by female and male emotional faces (joy, sadness, anger) taken from the RaFD (Langner et al., 2010). Additional emotions could be added according to the user's discrimination abilities (fear, surprise and disgust).	• Emotion discrimination - Difficulty level (number of pairs presented) - Number of rounds played - Time to match the different pairs in each round (time for each pair and total time) - Number of failures (mismatches) - Total playing time

Note. *The reward consisted in a blue and yellow bunny (the software's mascot) appearing in the centre of the screen with a shower of confetti and a clapping sound.
[1] All images were taken from the open and unrestricted library dataset "Unsplash" (https://unsplash.com).
[2] All faces images were taken from the Langner et al. (2010)'s *Radboud Faces Database* (RaFD) were used (Langner et al., 2010).

Table 4
Detailed presentation of the different serious games from the *Attention Eye* software used during the training phase (download link: https://tecfaetu.unige.ch/etu-maltt/aegir/elhamde0/vip/attention_eye/exe_attention_eye.zip).

	Description	Instructions	Illustration
Game 1 Social orienting	A moving shape is presented next to a human performing an activity (e.g. skater, dancer, guitarist). When the human is gazed at, a congratulation animation is triggered.	The experimenter encourages the user to look at the social protagonist: "Where's the skater/dancer/guitarist?"	
Game 2 Associating an emotion with its emotional prosody/emotion recognition	Two different emotions expressed by the same character are presented on screen coupled with the sound corresponding to the prosody of one of the two emotions. When the character whose emotion corresponds to the prosody heard is looked at, a congratulation animation is triggered.	The experimenter encourages the user to look at the character whose emotion corresponds to the prosody heard: "Where is the sad/happy/angry person?"	
Game 3 Response to joint attention	A character in the centre of the screen surrounded by two objects focuses his attention on one of them. When the user looks at this object, a congratulation animation is triggered.	The experimenter encourages the user to look at the object of joint attention: "Where is the character looking at?"	
Game 4 Socio-Moral evaluations	Several situations in which a character is in difficulty are presented (a person carrying a lot of books, climbing a mountain or standing in pouring rain). The player's gaze can be used to help the character to perform the action that puts him or her in difficulty.	The experimenter encourages the user to perform a pro-social action: "Oh, it's heavy, you've got to help him carry those books" for example.	

Note. In the four games, it was possible to set the following parameters: (a) the fixation time needed to validate an answer (seconds), (b) the size of the AOI to validate an answer (level of precision expressed as "approximate", "average" or "precise") and (c) the time until a game round was automatically validated when no answer was given (seconds). For each game, the number of rounds played and the number of successes/failures were automatically reported.

total time each AOI was gazed) within the whole screen area as well as within all the designated AOIs.

2.5.2. *Gaze rates, total dwell times (TDTs) and percentages of looking time (PLT)*

Visit durations within the whole screen area were then converted into *gaze rates* (expressed as percentages) by computing the ratio between the time spent looking at the screen regarding the blocks, tasks and the entire session over their respective durations. These percentages were used to investigate whether these gaze rates increased between T1 and T2.

On the other hand, *total dwell times* (TDTs) were calculated from the visit durations within the AOIs by summing up all dwells (set of one or more consecutive fixations in an AOI) recorded during each task's trials (excluding the invalidated ones of the RJA-Task). For each task we thus obtained the TDTs on both the type A stimulus and the type B stimulus that had been presented simultaneously. These paired TDTs were then converted into *percentages of looking time* (PLT), using the following equation:

$$\text{PLT on stimulus A} = \frac{\text{TDT on stimulus A}}{(\text{TDT on stimulus A} + \text{TDT on stimulus B})} * 100$$

2.6. Statistical analysis

All statistical analyses were conducted using TIBCO Statistica (version 13.2). A p-value $\leq .05$ was considered significant.

To investigate the quality of participants' visual exploration of the screen, we focused on gaze rates. We first performed nine paired-difference t-tests to test whether the overall session gaze rate increased between T1 and T2 in each participant. Then, we compared each task's gaze rates measured at T1 with those measured at T2 and investigated in more detail any individual progress by running paired t-tests again.

At both T1 and T2, discrimination abilities in each task were tested by comparing the PLT on stimulus A with the PLT on stimulus B in each of the nine participants by performing paired-sample t-tests.

Finally, to test whether the improvement between T1 and T2 was significant, we first calculated the difference in TDT between the two types of stimuli in each task at T1 and T2 and then compared the time difference scores of T1 with those of T2 by performing paired-difference t-tests.

Since the data from the control groups were collected at only one measurement time, they were subjected to only one type of statistical analysis: paired-difference t-tests were performed to test discrimination abilities by comparing the PLT on stimulus A with the PLT on stimulus B in each task for both groups.

Normality was tested using the Shapiro-Wilk W-test. It turned out that the 180 normality tests carried out with the data from the PIMD participants (a total of ten skills tested in nine participants at two measurement times) and the 20 tests carried out with the data from the two control groups all demonstrated the normality of the data (p-value associated with the Shapiro-Wilk W-test >0.05).

3. Results

Firstly, with regard to the participants' visual attention, analyses comparing the time each participant spent looking at the presentation screen during the different experimental sessions performed at T1 with T2 revealed that the nine participants looked at the screen significantly longer after the training phase (see Table 5).

Examining more closely the different types of stimuli that attracted participants' visual attention significantly more after the training phase, two tasks stood out from the others as having been gazed more at T2 by five participants: the GD-Task (by Zoé, Nina, Suzan, Betty and Tim) and the SME-Task (by Zoé, Nina, Suzan, Betty and Mike). The SO-Task attracted more attention from four participants at T2 (Zoé, Jane, Betty and Tim). The gaze rate for the RJA-Task was significantly higher at T2 for three participants (Zoé, Suzan and Jane).

Concerning emotional faces, on average this type of stimuli (both female and male faces) was gazed at significantly more at T2 by two participants (by Suzan and Elise). In more detail, female faces were more gazed at by two participants at T2 (by Suzan and Jane), whereas gaze rates for male faces did not increase significantly for any participant between T1 and T2.

Finally, only one participant, John, spent significantly more time looking at the PLM-Task stimuli at T2. In summary, looking at each case individually, Suzan had the most significant increase between T1 and T2 with five tasks being significantly gazed at more (emotional faces, female faces, GD-, RJA- and SME-Tasks). Zoé's gaze rates increased significantly at four tasks (SO-, RJA-, GD- and SME-Tasks), while three tasks attracted Jane and Betty's attention more at T2 (respectively SO-Task, female faces, RJA-Task and SO-, GD-, SME-Tasks). Nina and Tim's gaze rates increased significantly on two tasks (GD- and SME-Tasks for Nina, GD- and SO-Tasks for Tim). Finally, the following three participants gazed significantly more at a single task at T2: Elise (emotional faces), Mike (SME-Task) and John (PL-Task).

It is also interesting to note that, in general for PIMD individuals, the gaze rates measured at T2 (after the training phase) were closer to the gaze rates of the control group of TD children than to the rates measured at T1. In contrast, the gaze rates observed in the adult control group remained much higher.

The training phase also appears to have had a positive effect on participants' discrimination abilities in the various social-emotional tasks tested in the present study (see Table 6 for detailed results). Starting with preferential attention to biological motion, at T1 only four participants (Zoé, Nina, Elise and Mike) showed a significant preference for biological motion, whereas seven participants discriminated between the two types of motion at T2. By comparing the difference in time spent looking at each of the two types of paired stimuli at T1 with that at T2, the analysis revealed a significant progression in two participants (Nina and Jane). Interestingly, the TD children tended to look more at the biological motion than at the non-biological, but the difference was not significant. On the other hand, the adults showed a significant inverse visual preference as they looked longer at the non-biological motion.

Analyses of the SO-Task revealed that only three participants (Zoé, Nina and John) were able to discriminate between social and non-social scenes at T1, whereas all participants showed a significant preference for socially salient stimuli at T2, with a significant margin of improvement in seven of them. Similar to the results for individuals with PIMD at T2, TD children also showed a clear visual preference for socially salient stimuli. It is also interesting to note that this preference was also significant in TD adults but their percentages of looking time were more moderate for this type of stimulus than in TD children (73 % for social scenes in TD children vs. 58 % in TD adults).

Interestingly, all nine participants looked more at the eye area than at the mouth area of emotional faces at T1 and this preference was unchanged for all participants at T2. This visual preference for eyes was also found in the two control groups. The pairs of emotional faces revealed mixed results regarding participants' ability to discriminate different pairs of emotions. Firstly, for the ability to discriminate anger from joy, only two participants (John and Tim) showed a visual preference at T1 by looking longer at angry faces. In contrast, the other seven participants spent as much time looking at angry faces as happy ones at T1. Of these seven participants, only one (Jane) showed a significant preference for joy at T2. John and Tim's gaze times, which discriminated anger from joy at T1, were equivalent at T2. This visual preference for joy was also found in the control group of TD children, where the difference between the percentages of looking times within the two emotions was significant. Surprisingly, the results observed in the control group of TD adults were reversed, since they looked longer at happy faces than at the angry ones.

Regarding discrimination between joy and sadness, eight participants looked at both happy and sad faces equally at T1. Of these eight, only Betty seemed able to discriminate between these two emotions at T2, when she spent significantly more time looking at happy faces. Suzan, who was the only one to show a significant preference for joy at T1, had an opposite pattern at T2, with a non-significant tendency to look more at sadness. Finally, concerning discrimination between anger and sadness, the analyses revealed no significant preference at T1. However, at T2 three participants showed a visual preference: Nina and Betty gazed more at anger than at sadness, while Suzan spent more time gazing at sadness. Neither the TD children nor the TD adults showed any significant visual preference for either type of stimulus when discriminating between joy and sadness or between anger and sadness.

Next, with regard to joint attention capacities, the RJA-Task analyses showed that at T1 only two participants (Zoé and Nina) spent significantly more time looking at the objects looked at by the actress than at those not looked at, whereas this preference appeared in all the

Table 5
Comparison of the individual gaze rates (*M*, *SD*) (expressed in percentages) of the nine participants for the overall session and the different tasks tested at T1 and T2 using paired-difference *t*-tests. The gaze rates for the two control groups (TD children and TD adults) are also reported for comparison purposes.

–		T1			T2		Difference	
		N	M	(SD)	M	(SD)	t(n-1)	p
Overall session								
	#1 Zoé	7	62.26	(2.14)	77.03	(1.29)	−14.408	<0.001**
	#2 Nina	7	69.55	(3.65)	77.14	(1.89)	−4.928	0.003**
	#3 Suzan	6	48.97	(1.67)	58.21	(3.30)	−5.675	0.002**
	#4 Jane	7	55.72	(2.58)	63.44	(4.09)	−4.397	0.005*
	#5 Betty	6	51.79	(2.20)	57.04	(3.87)	−3.680	0.014*
	#6 Elise	7	55.28	(2.46)	65.59	(4.33)	−5.370	0.002**
	#7 Mike	6	67.68	(1.56)	74.73	(2.22)	−4.775	0.005*
	#8 John	7	62.65	(4.57)	70.58	(2.10)	−4.014	0.007*
	#9 Tim	7	58.01	(1.85)	64.26	(2.18)	−4.645	0.004**
	TD children	56			83.02	(7.99)		
	TD adults	101			93.48	(2.97)		
PLM-Task								
	#1 Zoé	7	72.72	(3.34)	75.48	(2.09)	−1.860	0.112
	#2 Nina	7	77.84	(2.82)	81.08	(4.57)	−1.345	0.227
	#3 Suzan	6	61.60	(1.03)	59.64	(2.53)	1.822	0.128
	#4 Jane	7	62.65	(2.07)	62.92	(3.61)	−0.216	0.836
	#5 Betty	6	61.90	(2.15)	60.20	(1.94)	1.148	0.303
	#6 Elise	7	62.24	(3.04)	63.54	(2.19)	−0.785	0.462
	#7 Mike	6	71.81	(2.86)	74.57	(4.24)	−1.056	0.339
	#8 John	7	71.42	(2.74)	77.86	(4.41)	−4.147	0.006*
	#9 Tim	7	68.45	(2.26)	66.54	(3.76)	1.572	0.167
	TD children	56			76.34	(16.86)		
	TD adults	101			92.59	(4.65)		
SO-Task								
	#1 Zoé	7	66.23	(4.28)	79.60	(2.72)	−5.943	0.001**
	#2 Nina	7	72.95	(5.75)	77.54	(5.08)	−1.807	0.121
	#3 Suzan	6	50.33	(9.36)	59.33	(6.29)	−1.674	0.155
	#4 Jane	7	53.16	(7.26)	66.69	(8.37)	−3.749	0.010*
	#5 Betty	6	56.81	(6.72)	66.33	(5.15)	−3.147	0.025*
	#6 Elise	7	60.66	(8.77)	68.18	(7.89)	−2.162	0.074
	#7 Mike	6	72.07	(3.96)	78.17	(7.97)	−1.643	0.161
	#8 John	7	70.58	(8.91)	78.38	(5.37)	−1.760	0.129
	#9 Tim	7	56.61	(4.37)	66.69	(7.81)	−2.775	0.032*
	TD children	56			85.58	(7.51)		
	TD adults	101			91.66	(1.49)		
Emotional faces								
	#1 Zoé	7	72.49	(2.46)	72.62	(3.29)	−0.068	0.948
	#2 Nina	7	73.01	(3.96)	73.57	(2.88)	−0.347	0.740
	#3 Suzan	6	53.28	(2.12)	60.88	(3.77)	−5.182	0.004**
	#4 Jane	7	54.63	(4.76)	59.82	(2.44)	−2.217	0.068
	#5 Betty	6	58.03	(3.44)	59.77	(3.60)	−2.484	0.056
	#6 Elise	7	58.02	(1.74)	63.95	(6.02)	−2.843	0.029*
	#7 Mike	6	72.55	(2.01)	72.54	(4.19)	0.002	0.998
	#8 John	7	69.45	(2.94)	70.95	(3.77)	−0.951	0.379
	#9 Tim	7	60.20	(1.84)	59.99	(3.66)	0.117	0.911
	TD children	56			82.90	(9.97)		
	TD adults	101			93.38	(2.03)		
Female faces								
	#1 Zoé	7	71.79	(4.21)	72.93	(3.73)	−0.444	0.672
	#2 Nina	7	73.09	(4.25)	74.88	(2.73)	−1.005	0.354
	#3 Suzan	6	52.43	(3.37)	63.19	(4.09)	−5.125	0.004**
	#4 Jane	7	54.48	(4.06)	60.92	(3.43)	−3.389	0.015*
	#5 Betty	6	57.77	(4.46)	57.50	(4.31)	0.192	0.855
	#6 Elise	7	58.37	(4.20)	64.08	(4.60)	−2.273	0.063
	#7 Mike	6	74.03	(2.68)	71.79	(6.28)	0.762	0.481
	#8 John	7	70.23	(4.34)	70.41	(4.30)	−0.085	0.935
	#9 Tim	7	62.81	(4.00)	60.58	(3.40)	0.910	0.398
	TD children	56			80.13	(14.42)		
	TD adults	101			93.36	(2.66)		
Male faces								
	#1 Zoé	7	73.18	(3.16)	72.31	(3.25)	0.480	0.648
	#2 Nina	7	72.94	(5.31)	72.26	(4.44)	0.263	0.801
	#3 Suzan	6	54.12	(4.73)	58.58	(5.75)	−1.802	0.131

(*continued on next page*)

Table 5 (*continued*)

–		T1			T2		Difference	
		N	M	(SD)	M	(SD)	t(n-1)	p
	#4 Jane	7	54.78	(6.38)	58.73	(3.48)	−1.271	0.251
	#5 Betty	6	58.29	(4.28)	62.03	(4.43)	−1.582	0.175
	#6 Elise	7	57.67	(2.71)	63.83	(8.24)	−2.332	0.058
	#7 Mike	6	71.06	(3.45)	73.29	(2.24)	−1.839	0.125
	#8 John	7	68.68	(2.55)	71.49	(5.12)	−1.280	0.248
	#9 Tim	7	57.59	(2.78)	59.41	(4.40)	−1.474	0.191
	TD children	56			85.66	(9.84)		
	TD adults	101			93.40	(1.99)		
RJA-Task								
	#1 Zoé	7	65.69	(4.88)	74.43	(4.71)	−3.968	0.007*
	#2 Nina	7	70.39	(7.69)	74.95	(4.38)	−1.587	0.164
	#3 Suzan	6	55.94	(2.94)	63.28	(5.34)	−3.896	0.011*
	#4 Jane	7	53.28	(3.19)	63.99	(6.64)	−4.864	0.003**
	#5 Betty	6	56.18	(4.47)	62.12	(8.46)	−2.259	0.073
	#6 Elise	7	67.05	(6.36)	63.76	(8.66)	0.696	0.513
	#7 Mike	6	71.42	(6.96)	72.41	(1.64)	−0.380	0.720
	#8 John	7	69.49	(7.39)	74.11	(6.24)	−1.000	0.356
	#9 Tim	7	62.31	(3.95)	63.95	(5.93)	−0.553	0.600
	TD children	56			82.76	(12.56)		
	TD adults	101			89.22	(8.60)		
GD-Task								
	#1 Zoé	7	69.41	(5.67)	83.38	(3.29)	−7.748	<0.001**
	#2 Nina	7	74.02	(5.28)	79.00	(2.18)	−3.080	0.022*
	#3 Suzan	6	47.24	(5.57)	58.79	(6.35)	−3.303	0.021*
	#4 Jane	7	53.65	(7.01)	64.10	(7.99)	−2.160	0.074
	#5 Betty	6	51.56	(2.95)	61.59	(6.02)	−2.991	0.030*
	#6 Elise	7	57.40	(9.12)	66.68	(6.76)	−1.690	0.142
	#7 Mike	6	72.16	(6.76)	73.81	(4.79)	−0.432	0.683
	#8 John	7	71.29	(9.14)	77.65	(4.69)	−1.548	0.173
	#9 Tim	7	57.93	(3.27)	67.66	(10.45)	−3.019	0.023*
	TD children	56			81.83	(16.92)		
	TD adults	101			89.90	(2.87)		
SME-Task								
	#1 Zoé	7	68.11	(6.11)	81.08	(2.93)	−4.540	0.004**
	#2 Nina	7	71.65	(6.58)	80.29	(6.16)	−2.932	0.026*
	#3 Suzan	6	56.14	(4.96)	65.13	(5.78)	−3.587	0.016*
	#4 Jane	7	58.00	(4.79)	66.75	(8.82)	−2.054	0.086
	#5 Betty	6	59.22	(6.84)	70.15	(6.89)	−2.581	0.049*
	#6 Elise	7	62.29	(6.94)	69.08	(7.61)	−1.524	0.178
	#7 Mike	6	67.08	(3.86)	79.06	(2.85)	−4.798	0.005*
	#8 John	7	66.50	(7.59)	69.92	(4.58)	−1.430	0.203
	#9 Tim	7	60.97	(7.24)	65.00	(3.02)	−1.376	0.218
	TD children	56			87.48	(8.71)		
	TD adults	101			93.65	(3.30)		

Note. Abbreviations: PLM-Task = Point-Light Motion-Task, SO-Task = Social Orienting-Task, RJA-Task = Response to Joint Attention-Task, GD-Task = Gaze Direction-Task, SME-Task = Socio-Moral Evaluation-Task.

* $p < .05$.

** $p < .005$.

participants at T2. Both TD children and TD adults also showed a significant visual preference for the objects looked at by the actress (with higher percentages for these objects measured in adults). Similarly, the GD-Task revealed that at T1 only two participants (Nina and John) preferred to follow the gaze movement of the face presented to them, whereas all participants showed this preference at T2. In the control groups, only the adults showed a significant visual preference for following the gaze direction of the face presented to them.

Finally, for the socio-moral evaluations, the analyses showed that only two participants discriminated between the prosocial and antisocial climbing scenes at T1: Zoé spent more time watching the prosocial scene and Tim spent more time watching the antisocial scene. At T2 all participants significantly preferred the prosocial scene with the exception of Zoé whose looking times towards each of the two scenes were statistically equivalent. Lastly, only one participant showed a significant preference for one of the two puppets at T1: Elise spent more time looking at the one that had performed a prosocial action compared to the one that had behaved anti-socially towards the climber. At T2, six participants (Nina, Jane, Elise, Mike, John ant Tim) showed the same visual preference for the prosocial puppet. No visual preference was observed in the two control groups: the TD children and the TD adults looked equally at the two climbing scenes (i.e. at the prosocial and at the antisocial one) and also looked equally at the two puppets (i.e. at the helper and at the hinderer).

4. General discussion

4.1. Main results

The aim of the present study was to evaluate the positive effects of a person-centred training using eye-tracking technology on the visual exploration and social-emotional abilities of children and adolescents

Table 6

Percentages of looking time (PLT) within the two stimuli types (A and B) of each task (M, SD) and statistical analysis (paired-difference *t*-tests) testing visual preferences of each of the nine PIMD participants at T1 (before the training phase) and at T2 (after the training phase) and calculation of the improvement between the two measurement times by comparing the time difference scores of T1 with those of T2 (paired-difference t-tests). The PLT and difference tests for the two control groups (TD children and TD adults) are also reported for comparison purposes.

	Pre-Training-test (T1)					Post-Training-test (T2)					Improvement			
	PLT on stimulus A	PLT on stimulus B		Difference		PLT on stimulus A	PLT on stimulus B		Difference		Diff score			
			ET	t(n-1)	*p*			*ET*	t(n-1)	*p*	M	*ET*	t(n-1)	*p*
PLM-Task (*Biological* vs *Non-biological* motion)														
#1 Zoé (n = 7)	62.265	37.735	*7.133*	4.549	0.004**	66.968	33.032	*6.736*	6.665	0.001**	−9.406	*10.400*	−2.393	0.054
#2 Nina (n = 7)	56.645	43.355	*7.132*	2.465	0.049*	67.731	32.269	*6.606*	7.102	< 0.001**	−22.173	*19.954*	−2.940	0.026*
#3 Suzan (n = 6)	53.611	46.389	*7.830*	1.130	0.310	58.013	41.987	*11.929*	1.645	0.161	−8.803	*23.643*	−0.912	0.404
#4 Jane (n = 7)	54.599	45.401	*9.526*	1.277	0.249	64.465	35.535	*5.112*	7.486	< 0.001**	−19.731	*15.683*	−3.329	0.016*
#5 Betty (n = 6)	53.247	46.753	*6.927*	1.148	0.303	59.159	40.841	*10.806*	2.076	0.093	−11.825	*20.807*	−1.392	0.223
#6 Elise (n = 7)	58.974	41.026	*4.716*	5.035	0.002**	66.080	33.920	*8.323*	5.112	0.002**	−14.212	*17.102*	−2.199	0.070
#7 Mike (n = 6)	60.238	39.762	*5.167*	4.853	0.005*	68.063	31.937	*9.530*	4.643	0.006*	−15.650	*28.189*	−1.360	0.232
#8 John (n = 7)	55.658	44.342	*8.404*	1.781	0.125	59.045	40.955	*7.269*	3.292	0.017*	−6.774	*24.384*	−0.735	0.490
#9 Tim (n = 7)	53.042	46.958	*10.986*	0.733	0.491	60.059	39.941	*4.165*	6.390	0.001**	−14.034	*21.906*	−1.695	0.141
TD children (*n* = 56)						52.287	47.713	*13.438*	1.274	0.208				
TD adults (*n* = 101)						47.848	52.152	*7.841*	−2.759	0.007*				
SO-Task (*Social* vs *Non-social* scenes)														
#1 Zoé (n = 7)	59.131	40.869	*7.665*	3.152	0.020*	68.661	31.339	*6.228*	7.927	< 0.001**	−19.059	*15.474*	−3.259	0.017*
#2 Nina (n = 7)	59.268	40.732	*6.007*	4.082	0.006*	70.588	29.412	*7.524*	7.239	< 0.001**	−22.640	*21.873*	−2.738	0.034*
#3 Suzan (n = 6)	55.194	44.806	*13.615*	0.934	0.393	60.958	39.042	*6.541*	4.103	0.009*	−11.528	*23.152*	−1.220	0.277
#4 Jane (n = 7)	47.876	52.124	*8.509*	−0.660	0.533	66.062	33.938	*8.982*	4.731	0.003**	−36.372	*17.651*	−5.452	0.002**
#5 Betty (n = 6)	53.487	46.513	*10.442*	0.818	0.451	67.733	32.267	*5.459*	7.957	0.001**	−28.491	*26.091*	−2.675	0.044*
#6 Elise (n = 7)	48.566	51.434	*8.415*	−0.451	0.668	64.208	35.792	*12.175*	3.088	0.021*	−31.283	*33.588*	−2.464	0.049*
#7 Mike (n = 6)	54.931	45.069	*5.670*	2.130	0.086	66.592	33.408	*9.593*	4.237	0.008*	−23.322	*20.096*	−2.843	0.036*
#8 John (n = 7)	63.785	36.215	*11.280*	3.233	0.018*	74.487	25.513	*11.337*	5.715	0.001**	−21.405	*24.228*	−2.337	0.058
#9 Tim (n = 7)	43.126	56.874	*8.746*	−2.080	0.083	62.210	37.790	*9.605*	3.363	0.015*	−38.169	*16.091*	−6.276	0.001**
TD children (n = 56)						73.127	26.873	*14.968*	11.562	< 0.001**				
TD adults (n = 101)						58.001	41.999	*15.676*	5.129	< 0.001**				
Face Exploration (*Eye* vs *Mouth*)														
#1 Zoé (n = 7)	80.015	19.985	*2.623*	30.270	< 0.001**	73.092	26.908	*5.579*	10.951	< 0.001**	13.846	*12.516*	2.927	0.026*
#2 Nina (n = 7)	78.044	21.956	*7.646*	9.704	< 0.001**	77.911	22.089	*5.148*	14.345	< 0.001**	0.266	*14.406*	0.049	0.963
#3 Suzan (n = 6)	79.464	20.536	*8.730*	8.267	< 0.001**	72.167	27.833	*9.872*	5.500	0.003**	14.593	*32.942*	1.085	0.327
#4 Jane (n = 7)	79.784	20.216	*8.559*	9.207	< 0.001**	73.810	26.190	*8.333*	7.560	< 0.001**	11.948	*21.261*	1.487	0.188
#5 Betty (*n* = 6)	77.076	22.924	*6.399*	10.364	< 0.001**	75.177	24.823	*6.219*	9.916	< 0.001**	3.797	*20.638*	0.451	0.671
#6 Elise (n = 7)	76.234	23.766	*7.034*	9.867	< 0.001**	74.288	25.712	*3.086*	20.820	< 0.001**	3.891	*16.835*	0.612	0.563
#7 Mike (n = 6)	75.128	24.872	*4.622*	13.316	< 0.001**	67.925	32.075	*6.724*	6.530	0.001**	14.406	*11.860*	2.975	0.031*
#8 John (n = 7)	77.979	22.021	*4.787*	15.465	< 0.001**	79.686	20.314	*5.822*	13.492	< 0.001**	−3.413	*18.179*	−0.497	0.637
#9 Tim (n = 7)	75.401	24.599	*5.086*	13.214	< 0.001**	77.276	22.724	*6.965*	10.362	< 0.001**	−3.751	*15.777*	−0.629	0.553
TD children (n = 56)						63.799	36.201	*20.565*	5.021	< 0.001**				
TD adults (n = 101)						66.565	33.435	*18.453*	9.022	< 0.001**				
Anger vs Joy Discrimination														
#1 Zoé (n = 7)	49.854	50.146	*9.411*	−0.041	0.969	49.493	50.507	*6.880*	−0.195	0.852	0.723	*23.745*	0.081	0.938
#2 Nina (n = 7)	51.023	48.977	*7.845*	0.345	0.742	51.026	48.974	*15.654*	0.173	0.868	−0.006	*36.484*	0.000	1.000
#3 Suzan (n = 6)	54.263	45.737	*11.951*	0.874	0.422	54.275	45.725	*10.064*	1.040	0.346	−0.023	*19.040*	−0.003	0.998
#4 Jane (n = 7)	50.803	49.197	*6.969*	0.305	0.771	56.581	43.419	*6.785*	2.566	0.043*	−11.556	*21.287*	−1.436	0.201
#5 Betty (n = 6)	49.774	50.226	*4.906*	−0.113	0.915	54.315	45.685	*13.003*	0.813	0.453	−9.081	*20.709*	−1.074	0.332
#6 Elise (n = 7)	48.935	51.065	*10.463*	−0.269	0.797	53.251	46.749	*7.072*	1.216	0.270	−8.633	*22.614*	−1.010	0.351

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Table 6 (*continued*)

	Pre-Training-test (T1)					Post-Training-test (T2)					Improvement			
	PLT on stimulus A	PLT on stimulus B		Difference		PLT on stimulus A	PLT on stimulus B		Difference		Diff score			
			ET	t(n-1)	*p*			*ET*	t(n-1)	*p*	M	*ET*	t(n-1)	*p*
#7 Mike (n = 6)	51.884	48.116	*6.475*	0.713	0.508	53.088	46.912	*6.189*	1.222	0.276	−2.407	*19.210*	−0.307	0.771
#8 John (n = 7)	59.661	40.339	*3.879*	6.589	0.001**	56.555	43.445	*7.179*	2.416	0.052	6.211	*14.150*	1.161	0.290
#9 Tim (n = 7)	61.069	38.931	*10.252*	2.857	0.029*	52.533	47.467	*8.168*	0.820	0.443	17.072	*32.208*	1.402	0.210
TD children (n = 56)						55.430	44.570	*11.911*	3.411	0.001**				
TD adults (n = 101)						47.560	52.440	*11.067*	−2.216	0.029*				
Joy vs Sadness Discrimination														
#1 Zoé (n = 7)	52.041	47.959	*5.806*	0.930	0.388	58.669	41.331	*12.264*	1.870	0.111	−13.255	*33.369*	−1.051	0.334
#2 Nina (n = 7)	57.011	42.989	*11.714*	1.584	0.164	61.580	38.420	*19.309*	1.587	0.164	−9.138	*49.336*	−0.490	0.642
#3 Suzan (n = 6)	61.094	38.906	*3.261*	8.334	< 0.001**	45.454	54.546	*11.993*	−0.929	0.396	31.281	*24.894*	3.078	0.028*
#4 Jane (n = 7)	55.547	44.453	*13.613*	1.078	0.322	51.698	48.302	*13.180*	0.341	0.745	7.698	*45.320*	0.449	0.669
#5 Betty (n = 6)	53.298	46.702	*8.780*	0.920	0.400	63.355	36.645	*12.148*	2.693	0.043*	−20.115	*22.376*	−2.202	0.079
#6 Elise (n = 7)	49.944	50.056	*11.283*	−0.013	0.990	48.292	51.708	*7.813*	−0.578	0.584	3.304	*27.854*	0.314	0.764
#7 Mike (n = 6)	48.048	51.952	*12.528*	−0.382	0.718	51.968	48.032	*8.653*	0.557	0.601	−7.841	*32.791*	−0.586	0.583
#8 John (n = 7)	51.564	48.436	*13.433*	0.308	0.768	50.796	49.204	*11.078*	0.190	0.856	1.537	*40.193*	0.101	0.923
#9 Tim (n = 7)	55.986	44.014	*14.538*	1.089	0.318	56.215	43.785	*11.265*	1.460	0.195	−0.457	*43.772*	−0.028	0.979
TD children (n = 56)						50.138	49.862	*12.640*	0.082	0.935				
TD adults (n = 101)						51.787	48.213	*9.990*	1.798	0.075				
Anger vs Sadness Discrimination														
#1 Zoé (n = 7)	51.011	48.989	*5.899*	0.453	0.666	51.780	48.220	*12.684*	0.371	0.723	−1.539	*29.965*	−0.136	0.896
#2 Nina (n = 7)	54.512	45.488	*8.260*	1.445	0.199	63.873	36.127	*12.184*	3.013	0.024*	−18.722	*30.979*	−1.599	0.161
#3 Suzan (n = 6)	57.892	42.108	*9.610*	2.012	0.100	37.151	62.849	*11.653*	−2.701	0.043*	41.482	*39.376*	2.581	0.049*
#4 Jane (n = 7)	47.619	52.381	*10.243*	−0.615	0.561	48.901	51.099	*5.403*	−0.538	0.610	−2.563	*24.143*	−0.281	0.788
#5 Betty (n = 6)	54.477	45.523	*13.921*	0.788	0.467	62.407	37.593	*8.927*	3.405	0.019*	−15.861	*36.910*	−1.053	0.341
#6 Elise (n = 7)	49.412	50.588	*13.477*	−0.115	0.912	53.726	46.274	*12.319*	0.800	0.454	−8.629	*27.888*	−0.819	0.444
#7 Mike (*n* = 6)	52.013	47.987	*7.378*	0.668	0.534	51.273	48.727	*7.337*	0.425	0.688	1.479	*28.395*	0.128	0.903
#8 John (n = 7)	57.765	42.235	*11.481*	1.789	0.124	40.891	59.109	*10.327*	−2.334	0.058	33.747	*38.579*	2.314	0.060
#9 Tim (n = 7)	52.298	47.702	*11.315*	0.537	0.610	56.493	43.507	*12.364*	1.389	0.214	−8.390	*43.474*	−0.511	0.628
TD children (n = 56)						49.884	50.116	*10.575*	−0.082	0.935				
TD adults (n = 101)						48.261	51.739	*10.236*	−1.707	0.091				
RJA-Task (*Looked-at* vs *Non-looked-at* objects)														
#1 Zoé (n = 7)	61.391	38.609	*9.144*	3.296	0.016*	72.711	27.289	*4.970*	12.090	< 0.001**	−22.641	*19.761*	−3.031	0.023*
#2 Nina (n = 7)	58.552	41.448	*5.099*	4.438	0.004**	75.664	24.336	*4.422*	15.354	< 0.001**	−34.223	*11.881*	−7.621	< 0.001**
#3 Suzan (n = 6)	55.946	44.054	*10.642*	1.369	0.229	73.936	26.064	*6.315*	9.285	< 0.001**	−35.980	*22.646*	−3.892	0.012*
#4 Jane (*n* = 7)	49.125	50.875	*5.263*	−0.440	0.675	69.786	30.214	*5.181*	10.103	< 0.001**	−41.323	*16.050*	−6.812	< 0.001**
#5 Betty (n = 6)	52.224	47.776	*12.044*	0.452	0.670	66.865	33.135	*9.024*	4.578	0.006*	−29.282	*28.329*	−2.532	0.052
#6 Elise (n = 7)	51.330	48.670	*10.668*	0.330	0.753	71.533	28.467	*4.652*	12.246	< 0.001**	−40.406	*20.285*	−5.270	0.002**
#7 Mike (n = 6)	56.873	43.127	*7.444*	2.261	0.073	70.248	29.752	*5.003*	9.914	< 0.001**	−26.750	*16.486*	−3.975	0.011*
#8 John (n = 7)	49.290	50.710	*6.852*	−0.274	0.793	71.614	28.386	*6.484*	8.819	< 0.001**	−44.648	*12.401*	−9.525	< 0.001**
#9 Tim (n = 7)	47.955	52.045	*9.554*	−0.566	0.592	65.645	34.355	*5.696*	7.266	< 0.001**	−35.380	*11.068*	−8.457	< 0.001**
TD children (n = 56)						64.757	35.243	*10.707*	10.314	< 0.001**				
TD adults (n = 101)						70.725	29.275	*13.769*	15.127	< 0.001**				
GD-Task (*Gaze followed* vs *Looked away*)														
#1 Zoé (n = 7)	49.203	50.797	*4.727*	−0.446	0.671	64.246	35.754	*5.252*	7.177	< 0.001**	−30.087	*19.145*	−4.158	0.006*
#2 Nina (n = 7)	55.935	44.065	*4.436*	3.539	0.012*	66.449	33.551	*9.926*	4.385	0.005*	−21.029	*21.192*	−2.625	0.039*

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Table 6 (*continued*)

	Pre-Training-test (T1)					Post-Training-test (T2)					Improvement			
	PLT on stimulus A	PLT on stimulus B		Difference		PLT on stimulus A	PLT on stimulus B		Difference		Diff score			
			ET	*t*(n-1)	*p*			*ET*	*t*(n-1)	*p*	M	*ET*	*t*(n-1)	*p*
#3 Suzan (n = 6)	47.246	52.754	*7.944*	−0.849	0.435	61.501	38.499	*4.325*	6.514	0.001**	−28.510	*15.030*	−4.647	0.006*
#4 Jane (n = 7)	49.202	50.798	*6.584*	−0.321	0.759	59.839	40.161	*5.962*	4.367	0.005*	−21.274	*21.817*	−2.580	0.042*
#5 Betty (n = 6)	51.339	48.661	*14.149*	0.232	0.826	64.706	35.294	*6.826*	5.277	0.003**	−26.735	*22.990*	−2.849	0.036*
#6 Elise (n = 7)	51.651	48.349	*10.499*	0.416	0.692	63.586	36.414	*6.640*	5.413	0.002**	−23.870	*21.769*	−2.901	0.027*
#7 Mike (n = 6)	55.122	44.878	*6.369*	1.970	0.106	60.509	39.491	*4.394*	5.859	0.002**	−10.774	*11.255*	−2.345	0.066
#8 John (n = 7)	54.983	45.017	*5.051*	2.610	0.040*	63.220	36.780	*6.950*	5.032	0.002**	−16.473	*16.554*	−2.633	0.039*
#9 Tim (n = 7)	53.486	46.514	*12.081*	0.763	0.474	61.167	38.833	*8.039*	3.675	0.010*	−15.362	*31.765*	−1.279	0.248
TD children (n = 56)						51.593	48.407	*10.598*	1.125	0.266				
TD adults (n = 101)						53.559	46.441	*8.717*	4.104	< 0.001**				
SME-Task (*Pro-social* vs *Anti-social* climbing scenes)														
#1 Zoé (n = 7)	55.307	44.693	*4.678*	3.001	0.024*	50.542	49.458	*3.904*	0.367	0.726	9.529	*12.523*	2.013	0.091
#2 Nina (n = 7)	51.120	48.880	*2.114*	1.402	0.211	52.718	47.282	*1.945*	3.699	0.010*	−3.197	*5.053*	−1.674	0.145
#3 Suzan (n = 6)	50.152	49.848	*5.170*	0.072	0.945	55.848	44.152	*2.310*	6.203	0.002**	−11.392	*8.236*	−3.388	0.020*
#4 Jane (n = 7)	49.473	50.527	*3.810*	−0.366	0.727	54.550	45.450	*3.758*	3.204	0.019*	−10.155	*10.365*	−2.592	0.041*
#5 Betty (n = 6)	48.148	51.852	*6.521*	−0.696	0.518	53.606	46.394	*1.835*	4.814	0.005*	−10.916	*13.963*	−1.915	0.114
#6 Elise (n = 7)	49.841	50.159	*4.625*	−0.091	0.930	54.522	45.478	*1.686*	7.095	< 0.001**	−9.362	*8.782*	−2.821	0.030*
#7 Mike (n = 6)	50.343	49.657	*5.592*	0.150	0.887	54.031	45.969	*2.521*	3.916	0.011*	−7.376	*14.157*	−1.276	0.258
#8 John (n = 7)	49.807	50.193	*3.952*	−0.129	0.902	55.525	44.475	*1.469*	9.952	< 0.001**	−11.435	*7.197*	−4.204	0.006*
#9 Tim (n = 7)	45.194	54.806	*1.139*	−11.165	< 0.001**	54.239	45.761	*1.232*	9.103	< 0.001**	−18.091	*4.063*	−11.779	< 0.001**
TD children (n = 56)						50.938	49.062	*4.194*	1.442	0.155				
TD adults (n = 101)						50.081	49.919	*2.136*	0.379	0.705				
SME-Task (*Pro-social* vs *Anti-social* puppets)														
#1 Zoé (n = 7)	52.723	47.277	*7.851*	0.918	0.394	37.426	62.574	*14.905*	−2.232	0.067	30.594	*26.889*	3.010	0.024*
#2 Nina (n = 7)	54.045	45.955	*10.478*	1.021	0.347	67.008	32.992	*7.288*	6.174	0.001**	−25.926	*19.484*	−3.521	0.013*
#3 Suzan (n = 6)	56.714	43.286	*14.077*	1.168	0.295	58.441	41.559	*10.188*	2.029	0.098	−3.454	*35.001*	−0.242	0.819
#4 Jane (n = 7)	48.582	51.418	*10.107*	−0.371	0.723	60.288	39.712	*7.581*	3.591	0.011*	−23.413	*22.028*	−2.812	0.031*
#5 Betty (n = 6)	52.894	47.106	*11.669*	0.608	0.570	57.661	42.339	*9.138*	2.053	0.095	−9.532	*21.940*	−1.064	0.336
#6 Elise (n = 7)	60.409	39.591	*7.937*	3.470	0.013*	59.954	40.046	*2.670*	9.864	< 0.001**	0.911	*16.553*	0.146	0.889
#7 Mike (n = 6)	52.089	47.911	*15.356*	0.333	0.753	59.685	40.315	*5.961*	3.980	0.011*	−15.193	*37.813*	−0.984	0.370
#8 John (n = 7)	61.272	38.728	*12.481*	2.390	0.054	66.838	33.162	*10.221*	4.358	0.005*	−11.131	*40.504*	−0.727	0.495
#9 Tim (n = 7)	49.666	50.334	*16.051*	−0.055	0.958	61.920	38.080	*9.093*	3.468	0.013*	−24.507	*40.653*	−1.595	0.162
TD children (n = 56)						51.843	48.157	*8.978*	1.536	0.130				
TD adults (n = 101)						50.487	49.513	*8.282*	0.591	0.556				

Note. Abbreviations: PLM-Task = Point-Light Motion-Task, SO-Task = Social Orienting-Task, RJA-Task = Response to Joint Attention-Task, GD-Task = Gaze Direction-Task, SME-Task = Socio-Moral Evaluation-Task.

* $p < .05$.

** $p < .005$.

with PIMD. Using a pre-training – training – post-training design, this single-case pilot study demonstrated the benefits of a training phase implemented over a one-year period in these individuals. Indeed, the results comparing participants' individual visual exploration and discrimination abilities at T1 with those at T2 highlighted the positive effects of the training phase: all participants considerably improved their visual exploration between T1 and T2. In addition, they all made significant progress on at least one of the six social-emotional competencies assessed.

The findings obtained from the two control groups further reinforce the results observed in the PIMD participants before and after the training phase. Firstly, in terms of visual exploration of the screen, it is noteworthy that gaze rates in the PIMD participants at T2 more closely resembled those of TD children than at T1, suggesting the effectiveness of the training phase. Secondly, concerning social-emotional abilities, and more specifically discrimination capacities, the results of the two control groups also provide additional insights into the individual performances of PIMD participants.

First of all, although the TD children did not show significant results in the PLM-Task, their gaze patterns still suggested a tendency to prefer biological motion, similar to what was observed in the nine PIMD participants. Surprisingly, a reversed visual preference was observed in the TD adult group who looked significantly longer at non-biological motion than at biological motion, a result inconsistent with prior literature on biological motion perception in humans (Hemeren & Rybarczyk, 2020).

For the SO-Task, we found that, unlike at T1, all PIMD participants showed a significant visual preference for socially salient stimuli at T2, consistent with the preferences observed in the two control groups. Interestingly, TD children showed a particularly high interest in social scenes compared with adults, whose average percentage of looking time was lower. This difference is likely attributable to the nature of the stimuli, which featured dynamic scenes of solo dancing children.

Additionally, most PIMD participants showed a tendency to look more at anger than joy at T2, a pattern also found in TD children, where the difference between the two emotions was statistically significant. However, the opposite trend was observed in TD adults, who looked longer at happy faces than angry faces, in line with previous findings (Hunnius et al., 2011). When testing discrimination between joy and sadness, as well as between anger and sadness in PIMD individuals, few significant results were observed at either measurement time. Similar results were obtained in the control groups: neither the TD children nor the TD adults exhibited significant visual preferences when distinguishing between these emotions.

Regarding the RJA-Task, only two PIMD participants exhibited a visual preference for the objects looked at by the actress at T1, whereas all nine participants demonstrated this preference at T2, as did both control groups.

Similarly, for the GD-Task, only two PIMD participants followed the gaze direction of the presented face at T1, whereas all nine participants showed this preference at T2. Interestingly, in the control groups, this preference was only observed in adults, as untrained TD children aged 1 to 3 years appeared to struggle with this task.

Finally, in the SME-Task, the absence of significant results in the two control groups was unexpected and difficult to explain. However, in a previous study demonstrating the feasibility of an earlier version of the experimental paradigm used in the present study, a control group of 32 TD children (aged 1–3 years) similarly showed no significant preference for either of the two puppets presented (Cavadini et al., 2022).

4.2. Methodological considerations on control groups

This pilot study included two comparison groups composed of typically developing individuals: 56 children (aged around two years, corresponding to the estimated developmental age of the PIMD participants) and 101 neurotypical adults. These groups were tested at a single time point to provide a reference baseline for expected cognitive and social-emotional abilities in typically developing populations. This approach allowed for a more meaningful interpretation of the results observed in PIMD participants. Unlike PIMD individuals, the typically developing groups were not assessed twice, as they did not undergo training. This decision was both methodologically justified – since the training was specifically designed for PIMD needs and was not applicable to typically developing individuals – and logistically necessary, as the training materials were not adapted for this population.

Moreover, a within-population control group of untrained PIMD participants was not included. This decision was based on several considerations. First, the study was designed as a single-case analysis, focusing on individual progress rather than group comparisons. Given the extreme heterogeneity of PIMD profiles, a comparison between a trained and untrained group would have been methodologically problematic due to inter-individual variability. Second, from an ethical standpoint, it would have been questionable to withhold a potentially beneficial intervention from a subset of participants. Finally, recruiting additional PIMD participants would have been highly challenging. If such recruitment had been feasible, it would have been preferable to include these individuals in the training phase to enhance sample size and strengthen conclusions.

4.3. Implications at theoretical and clinical levels

Altogether, the findings of the present study have major implications at both theoretical and clinical levels. From a theoretical perspective, this study reinforces the notion that individuals with PIMD, much like typically developing children, possess learning abilities regardless of their chronological age. The experimental tasks and serious games used in this study were specifically designed to enhance various levels of information processing involved in perceptual learning, ranging from fundamental perceptual abilities to more complex cognitive functions. These include distinguishing objects from their background, detecting essential features such as color, shape, and movement, understanding spatial positioning, and recognizing interrelations between stimuli. These perceptual and cognitive processes rely on core mechanisms such as attention, visual discrimination, categorization, working memory, long-term memory, and decision-making. In turn, cognition influences visual perception (Kellman, 2002), shaping how individuals interpret and interact with their environment. The ability to detect similarities and differences among stimuli forms the foundation for internal representations of the world and serves as a precursor to the development of knowledge. By demonstrating that individuals with PIMD can develop and refine these cognitive skills, this study challenges the longstanding perception that this population lacks meaningful learning potential and highlights the importance of tailored interventions to foster their cognitive and social-emotional development.

From a clinical perspective, these results underscore the necessity of developing assessment and intervention tools tailored to the specific needs of individuals with PIMD. By designing tasks that target different aspects of perception and cognition, it is possible to construct more precise and comprehensive cognitive profiles for each individual, thus addressing the critical need for improved assessment methods in this population (Nakken & Vlaskamp, 2007). The integration of eye-tracking technology in this context offers a non-invasive and objective means of evaluating socio-emotional and perceptual abilities in individuals with limited verbal and motor responses. This contributes to a broader shift towards evidence-based and technology-assisted approaches in the field of special education and rehabilitation (Cavadini & Gentaz, 2023).

However, while eye-tracking presents promising applications, it is important to recognize that it is not the only modality available for supporting social-emotional learning in individuals with PIMD. Alternative assistive technologies, such as touch-based or auditory interactive devices, may be more suitable for certain individuals depending on their sensory and motor profiles (Wilkinson & Mitchell, 2014). A multi-modal approach that integrates different technological solutions could prove particularly beneficial in addressing the heterogeneous needs of this population. Future research should explore how eye-tracking can be effectively combined with other assistive modalities to create more adaptable and inclusive intervention strategies. Expanding the discussion on how eye-tracking compares to and complements other assistive technologies would provide a more comprehensive understanding of its role within the broader landscape of technology-assisted interventions for individuals with PIMD.

4.4. Limitations and future directions

4.4.1. The question of skill transfer and ecological validity

The question of skill transfer and its ecological validity is a crucial aspect to consider when assessing the long-term impact of the training implemented in this study. Transfer of learning refers to the ability to apply knowledge or skills acquired in one context to a different situation (Marini & Genereux, 1995). However, there is little consensus on its precise definition (Barnett & Ceci, 2002). Some studies define it as "the carrying over of an act or way of acting from one performance to another" (Woodworth & Schlosberg, 1954), while others describe it as "the ability to extend what has been learned in one context to new contexts" (Bransford, Brown, & Cocking, 2000). The nature of transfer is often discussed in terms of *near* and *far* transfer. Near transfer occurs when learned skills are applied to a similar context, whereas far transfer involves generalizing skills to a different and dissimilar domain (Perkins & Salomon, 1992). The distinction between these two types of transfer remains debated, with some researchers arguing that far transfer is rare or difficult to achieve, while others suggest that the conditions under which transfer occurs must be carefully examined.

In this pilot study, we did not directly assess the generalization of learning beyond the training context. However, the cognitive skill profiles established through the ECP (Evaluation-Cognition-PIMD) scale at multiple time points (one-year pre-study, T0, T1, and T2) suggest the presence of near and proactive transfer of knowledge. As illustrated in Table 2 (cf. Methods section), all participants demonstrated greater progress across ECP subscales between T1 and T2 compared to the period between T0 and T1, suggesting that training effects extended beyond the immediate context of the eye-tracking tasks.

Despite these promising findings, it remains essential to investigate whether the observed improvements translate into meaningful functional gains in participants' real-world environments. In other words, does progress in gaze-based serious games reflect actual enhancements in social interactions, attentional engagement, and emotion recognition in everyday settings? This concern is analogous to questioning whether achieving high scores in a virtual cooking game corresponds to actual cooking proficiency. The discrepancy between game-based success and real-world functionality is a well-documented challenge in digital interventions (Blumberg et al., 2024), and further research is needed to explore how these skills manifest outside the training context.

One key limitation in this study is the absence of social validity assessments that could provide further insights into real-world skill application. While the ECP scale offers structured clinical data, complementary approaches such as direct behavioral observations, caregiver reports on daily social interactions, or ecological assessments in naturalistic settings would enhance our understanding of how trained skills are applied beyond the experimental paradigm. Integrating such measures in future studies would allow for a more comprehensive evaluation of both standardized improvements and practical outcomes.

Another avenue for addressing skill transfer is the consideration of support systems that facilitate the application of learned abilities. Individuals with PIMD often rely on structured social and environmental scaffolding to reinforce and generalize their skills (Granlund, Wilder, & Almqvist, 2013). Understanding how caregivers, educators, and therapists can help sustain the effects of gaze-based training in daily interactions is crucial. Additionally, ensuring that training interventions align with participants' real-world needs and daily routines may improve the likelihood of skill generalization.

Future research should prioritize longitudinal follow-ups and mixed-methods approaches to better capture the ecological validity of training outcomes. This could include conducting structured assessments several months after training completion to examine whether improvements are maintained over time and to what extent they transfer to real-world settings. Additionally, qualitative analyses of participant engagement and caregiver perceptions could provide valuable insights into the subjective experience and practical impact of gaze-based interventions.

In summary, while this study provides encouraging evidence of near transfer, further research is needed to bridge the gap between experimental progress and real-world functioning. Combining structured assessment tools with social validity measures and longitudinal observations would strengthen the evidence base, offering a more nuanced understanding of how gaze-based training can meaningfully improve the daily lives of individuals with PIMD.

4.4.2. Need for individualized progress analysis and long-term follow-up

Another limitation of this pilot study concerns the interpretation of training effects and the difficulty in precisely identifying how each serious game contributed to the observed improvements in social-emotional abilities. The person-centered training approach adopted in this study allowed the experimenter to select from a diverse set of serious games, tailoring the sessions to each participant's current health status, level of alertness, personal skills, and specific needs.

This individualized approach was crucial for maintaining engagement and optimizing learning outcomes, given the heterogeneity of the PIMD population. However, this flexibility also introduced variability across participants, making it difficult to systematically analyze the effects of each specific game. Consequently, training effects were primarily assessed through participants' discrimination abilities at T2 compared to T1, without an in-depth analysis of their progression across specific games. A relevant future direction would be to conduct a detailed, session-by-session analysis of each participant's progress within different serious games over time, providing valuable insights into the learning trajectories of participants. Monitoring key performance indicators across training sessions – such as gaze engagement, response accuracy, or progression within game tasks – could help disentangle the effects of different training components and identify which game mechanics are most effective for fostering socio-emotional development. Additionally, such an approach could allow for a more adaptive and data-driven refinement of training programs, ensuring that interventions are continuously optimized to meet the evolving needs of each participant. Beyond session-level monitoring, integrating more structured progress-tracking tools – such as automated performance logs, experimenter-coded behavioral responses, or individualized adaptation of game difficulty – could enhance the granularity of training assessments. This type of in-depth evaluation would not only help refine future interventions but also contribute to a broader understanding of how gaze-based technologies can be leveraged to support learning in individuals with PIMD.

In addition, a long-term follow-up would be essential to assess the durability of the observed learning gains and their potential generalization beyond the training context. Follow-up evaluations, ideally conducted several months post-intervention, would offer valuable insights into the sustainability of these improvements. However, conducting such an evaluation requires the use of longitudinal assessment tools and sustained collaboration with professionals, which proved to be particularly challenging in the present pilot study. One major constraint was the high staff turnover within the MEI, reflecting a structural issue in healthcare and social assistance sectors in our country. Medical-social institutions face a chronic shortage of qualified personnel, exacerbated by demanding working conditions, low salaries, and a lack of professional recognition (Haute Autorité de la Santé [HAS], 2020). Moreover, the high turnover of temporary staff complicated the continuity of care. This workforce instability directly impacted our ability to obtain in-depth feedback on participants' performance outside the training sessions, as short-term staff members lacked both in-depth knowledge of the participants and familiarity with the ongoing research project. Future research should address this gap by integrating longitudinal assessments, allowing researchers to evaluate the retention and potential decline of acquired skills. Such data would be crucial for understanding the long-term impact of gaze-based training and for optimizing intervention strategies.

5. Conclusion

In conclusion, by making the training software used in this pilot study freely available, we enable professionals and caregivers to explore its potential benefits for individuals with PIMD. This is particularly important for caregivers and educators working with this population, where progress is often slow and difficult to detect, and where delays in regression may already be regarded as positive outcomes (Nakken & Vlaskamp, 2007). This approach aligns with recent public health recommendations from various European countries (HAS, 2020; Lawton, 2009). Future research should further explore longitudinal follow-ups and alternative assistive technologies, including haptic and auditory interfaces, to broaden access to individualized learning interventions for individuals with PIMD.

CRediT authorship contribution statement

Thalia Cavadini: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yannick Courbois:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Edouard Gentaz:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Thalia Cavadini reports financial support was provided by Swiss National Science Foundation. 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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2025.104928.

Data availability

Data have been disseminated as supplementary material attached to the manuscript

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