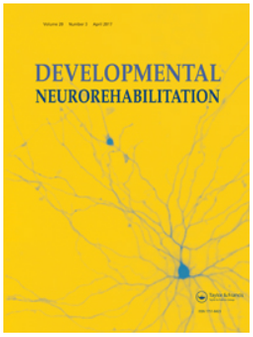

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ORIGINAL ARTICLE

Gaze-based assistive technology in daily activities in children with severe physical impairments–An intervention study

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ABSTRACT

Objective: To establish the impact of a gaze-based assistive technology (AT) intervention on activity repertoire, autonomous use, and goal attainment in children with severe physical impairments, and to examine parents' satisfaction with the gaze-based AT and with services related to the gaze-based AT intervention. *Methods*: Non-experimental multiple case study with before, after, and follow-up design. Ten children with severe physical impairments without speaking ability (aged 1–15 years) participated in gaze-based AT intervention for 9–10 months, during which period the gaze-based AT was implemented in daily activities. *Results*: Repertoire of computer activities increased for seven children. All children had sustained usage of gaze-based AT in daily activities at follow-up, all had attained goals, and parents' satisfaction with the AT and with services was high. *Discussion*: The gaze-based AT intervention was effective in guiding parents and teachers to continue supporting the children to perform activities with the AT after the intervention program.

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Cerebral palsy; computer activities; eye-tracking technology; goal achievement; self-help devices

Introduction

Using computers as assistive technology (AT) has been found to be an important intervention for children with profound impairments since it can reduce participation restrictions and activity limitations in childhood activities,[1,2] especially in the areas of play, education, and communication.[3] Cerebral palsy is the most common cause of physical impairments in children, and the prevalence is two per 1000 live births.[4] Consequently, children with severe impairments represent a small group among the children with cerebral palsy. Only about one-third of these children have a severe motor impairment[5] and about 25% are nonverbal .[6,7] It is known that children with severe physical impairments, without speech, become involved in fewer activities with less diversity, and their activities are most often related to the home.[8,9] They tend to have limited opportunities for social interaction.[10] Any intervention that will support these children to become active, spend time in a variety of activities, and give them opportunities to explore activities may support the children's development and therefore needs to be prioritized. An AT has the purpose of increasing the repertoire of activities a person can perform independently or with greater ease,[11] which is why AT ought to be an effective intervention for this child group.

In accordance with the well-known definition by the International Organization for Standardization,[12] AT can be seen as an assistive product that is used to prevent activity limitations or participation restrictions. Controlling a computer with eye gaze, i.e., a gaze-based AT, may be the only way to operate a computer for children who have such severe physical impairments that they cannot fully control any other body movements than their gaze. Gaze-based AT has the potential to enable these children to perform childhood activities, such as to play and to interact with others. However, there is a dearth of studies investigating this subject area. Only a few case studies have been published concerning children with severe physical impairments and the use of gaze-based AT for daily activities.[13–16] For children with profound impairments, user trials have found gaze-based AT to be suitable for activities such as playing music and games[13,15] and making drawings.[17] For example, a child with severe motor impairment could use a gaze-based AT in primary school for music and story activities.[14] In a case study[16] gaze-based AT was used for literacy training and for communication among the children involved (aged 7 and 9 years). Activity repertoire or fulfillment of goals for gaze-based AT use was not reported. However, at the 3 months follow-up after provision, it was not used to its full potential in daily life, due to the lack of support in implementing the gaze-based AT in daily activities. The need of support, guidance, and training in adapting the AT to the child's needs over time, as well as

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the need of ongoing technical support, has been stressed in research as facilitating factors of service delivery to promote the implementation and use of AT in daily activities.[16,18–20]

An AT intervention consists of having access to the AT and to services provided by practitioners to integrate and promote the use of the AT in daily life.[21] Research has reported that not all AT provided for children with impairments is used in daily life.[22,23] It has been pointed out that long-term services are often needed to promote the continued use of AT over time, for example for communication, for children with profound impairments.[24,25] The use of AT for communication by children with severe physical impairments has been described as an evolving process over time, with high motivation and use during the initial months, followed by reduced motivation and usage between 3 and 6 months after provision of the AT.[25]

According to the Human Activity Assistive Technology (HAAT) model, the AT usage will be determined by the dynamic interaction between the human, the activity, and the AT within the specific environment of use. Each of these components has the potential to enable or disable performance with the AT.[26] AT usability can be understood as the product of the interplay between these components,[27] and usability is defined as the degree to which a user can use an AT to fulfill goals with effectiveness (e.g., completeness of specified goals with AT use), efficiency (e.g., time and effort during performance), and with satisfaction when using the AT in a specific context of use.[28]

The activity is described as the fundamental element in the HAAT model,[26] and in line with this model the present study highlights the relevance of the activity to the person as the paramount and performing activities as the overall goal of using the AT. Thus, the use of the AT, activity repertoire as well as achievement of goals for AT use is important outcomes to measure. AT usage is commonly measured based on the type of activities, frequency, and duration of AT use, in addition to the specific contexts in which it is used.[27,29] Continued use of an AT can be predicted by the AT usability, as the AT needs to be usable to have continued use over time.[27] Furthermore, a usable AT is a prerequisite to be useworthy in daily life.[11] In accordance with research in other areas of AT,[30] usage needs to be measured for a long period of time to capture the longitudinal usability of gaze-based AT.

Most research concerning the use of gaze-based AT for daily activities has been conducted on adults with severe physical impairments, and shows usage for activities such as communication and internet surfing.[31–33] These survey studies focused on communication activities, quality of life, and satisfaction with the gaze-based AT mostly with experienced users. In research on children, case studies indicate that gaze-based AT has the potential to support children to perform activities.[13,14,16,17] In a longitudinal study by Borgestig et al.,[34] the efficiency of gaze-based AT for children with severe physical impairments without speech was measured in a standardized environment. They found eye gaze performance to improve over time with respect to time-on-task and accuracy after long-term practices. In addition, environmental aspects that have an impact on the use of gaze-based AT for children with physical impairments have been investigated.[16] However, research that evaluates activity repertoire and the use of gaze-based AT in daily activities over time for children with profound impairments is lacking.[15,35] This may be because gaze-based AT is an underutilized AT for children with profound impairments, and until recently, it has been an expensive AT. Researchers have also emphasized the need to investigate what support is required to support its use in daily activities over time.[35] The aim of the present study was therefore to establish the impact of a gaze-based AT intervention on activity repertoire, autonomous usage, and goal attainment in children with severe physical impairments. In addition, parents' satisfaction with the gaze-based AT and with services related to the gaze-based AT intervention was examined.

Materials and methods

This nonexperimental multiple case study used a before, after, and follow-up design[36] including 10 children with severe physical impairments without speaking abilities. The data were collected daily during a 14-day period at baseline (A), post-intervention (B_1), and at follow-up (B_2) for the computer-use variables (activity repertoire, duration of use, percentage of days with use, and number of performed activities). Intervention lasted for 9–10 months, and follow-up was conducted 5–10 months after withdrawal of the services related to the gaze-based AT intervention, as shown in Figure 1.

Study context

A regional pediatric rehabilitation center (RPC) in Sweden has a multi-professional communication (MPC) team specializing in the use of AT, such as gaze-based AT. Local services, such as local pediatric rehabilitation centers, can refer children up to 18 years with physical impairments and complex communication needs to receive support in assessment,

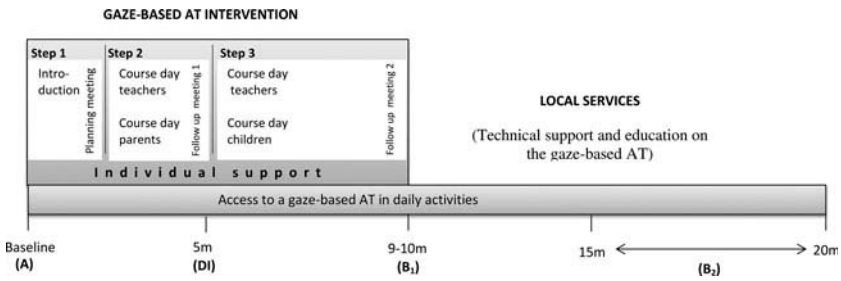

Figure 1. Format of gaze-based AT intervention, and time points for data collection (in months), DI (during intervention), B_1 (post-intervention), and B_2 (follow-up). As expected, the children were provided with local services between B_1 and B_2, 0–5 occasions to parents (mean 1.9), 1–10 occasions to teachers (mean 3.8).

Table 1. Background variables for participating children.

Participant, sex, and age (in years)	Diagnosis*	GMFCS, MACS, CFCS[§]	Epilepsy	Cognition[£]	Vision and hearing[£]	Parents' native language	Siblings	School[£]
1. Emma ♀, 1	High CSCI	NA[£]	No	N	N	Swedish"	1	NA
2. Jacob ♂, 5	CP dyskinesia	IV, V, IV	Yes	N	Hearing loss, no hearing aid	Swedish"	2	Special preschool
3. Daniel ♂, 6	CP dyskinesia	IV, IV, IV	No	Unknown	Refractive error, bilateral hearing loss, no hearing aid	Not Swedish"	3	Mainstream school, special class
4. Max ♂, 6	CP dyskinesia	IV, IV, IV	Yes	UI	N	Not Swedish"	4	Special school
5. Adam ♂, 8	CP spastic diplegia	IV, V, IV	No	UI	N	Swedish"	2	Special school
6. Isaac ♂, 8	CP spastic diplegia	V, V, IV	No	Unknown	Alternating strabismus	Swedish"	2	Special school
7. David ♂, 9	CP spastic diplegia	V, V, V	Yes	UI	Refractive error, eye glasses	Not Swedish"	1	Special school
8. Lucas ♂, 13	CP spastic tetraplegia	V, IV, IV	Yes	UI	Alternating strabismus	Swedish"	1	Special school
9. Marcus ♂, 15	CP dyskinesia	V, IV, IV	No	N	N	Swedish"	2	Mainstream school, special class
10. Anna ♀, 15	CP spastic tetraplegia	V, V, V	No	UI	N	Swedish"	1	Special school

*CSCI, Cervical spinal cord injury; CP, Cerebral palsy.
[§]GMFCS, Gross Motor Function Classification System [50]; MACS, Manual Ability Classification System [51]; CFCS, Communication Function Classification System [52]. Level I-V, with level V as most restricted ability.
[£]NA, Not appropriate; N, Normal; UI, Unspecified cognitive impairment; Unknown, not possible to assess.

training, and adaptation of gaze-based AT usage and to take part in the specific gaze-based AT intervention under study, with the purpose of integrating the gaze-based AT in the children's everyday life. The MPC team consisted of an occupational therapist, speech and language pathologist, special education teacher, and IT support person. All were well-trained in the adaptation and usage of gaze-based AT. A pediatric neurologist was involved as a medical expert. The speech and language pathologist and the special education teacher both had more than 10 years of experience in servicing the target group.

Participants

A total of 10 children were referred to the regional pediatric center in 2010–2013 with requests for support of the children's use of gaze-based AT. Inclusion criteria for the current study were: (a) children with severe physical impairments without speaking ability, (b) up to 18 years, (c) with access to gaze-based AT, and (d) whose parents and teacher agreed to participate in the gaze-based AT intervention and in data collection. All parents of the 10 children consented to participation, and all children were recruited. One teacher of each child was invited to participate and all consented to participation. Participating children are described in Table 1. All children communicated with facial expressions and eye-pointing (e.g., point to show interests or to request items, some could express yes/no by for example look up/down) as no one could speak or communicate with sign language. The children had access to low-tech communication boards (n = 4) or single pictures (n = 4) for communication, but they were reported to be seldom used. Some children also had additional impairments, such as unspecified cognitive impairments (five children), strabismus (two children), and epilepsy (four children). Among the seven children with unknown cognitive level or with unspecified cognitive impairment, three could clearly express yes/no by eye-pointing (children 3, 5, 8), three were unclear in this (children 4, 6, 10) whereas one child could not (child 7). The teacher to this child (7) used real objects as symbols and the child was in the beginning of learning to use pictures for communication. The other children used pictures for communication.

Seven children were provided with a gaze-based AT at baseline. Three children already had access to a gaze-based AT and needed support to start to use it. Two had had other computer access methods at baseline but were assessed not to be able to develop more with the hand switch (child 10) or the head-controlled mouse (child 5) due to their profound motor impairment. The mean age of the parents was 40.7 years (SD 4.9). Parents to three children had another native language than Swedish but all could understand and speak some Swedish. However, interpreters were used during the whole process for these three settings. Teachers had between nine and 39 years of experience in the profession (mean 20, SD 9) (eight women, two men). The children are identified in the results with numbers (1) to (10) or fictional names.

The gaze-based AT intervention

The gaze-based AT intervention consisted of two parts: having access to gaze-based AT and having access to the services from the MPC team. When the gaze-based AT intervention ended (after 9–10 months), the services of the MPC team were terminated. The children then continued to have full access to the gaze-based AT in their daily lives.

The gaze-based AT

The children had access to the gaze-based AT Tobii C12 (nine children) or P10 (one child) (built-in gaze devices).[37] Both devices are portable and were mounted on a floor stand, table stand, or on the wheelchair. The gaze-based AT was transported with the child between home and school. During the intervention program, the software in the gaze-based AT was adapted to include dynamic communication pages with pictures, symbols, and speech output, to meet each child's individual needs at home and/or at school. Due to different ages and cognitive levels, pages were developed for play and leisure, for educational tasks, and to communicate. The number of pictures

Figure 2. A personalized first page in the gaze-based AT, from which the child can select a picture with eye gaze to reach more pages with pictures and activities.

on a page varied between 3 and 25, with a variation of between 60 and 800 pictures in total when the children ended the intervention program (for an example of a page, see Figure 2).

The services

The services were based upon the same research-based key elements (increase knowledge among teachers, collaboration between key persons, child's preferences for usage, and goal setting), format (course day and planning meeting), and modular content areas, as in a previous study by Borgestig, Falkmer, and Hemmingsson.[38] The measures used for the evaluation of computer usage were also tested in that study (e.g., computer use diaries, goal attainment with computer use). Due to the children's profound impairments, the current study added individual support.

The services were provided by the MPC team over a period of 14 days, spread across 9–10 months. The purpose of the services was to optimize the implementation and use of gaze-based AT in daily activities. The current study involved parents and all key persons (i.e., all that played a role in the child's use of gaze-based AT in daily life) in joint goal-setting, planning, and jointly reviewing the progress of the use of gaze-based AT at home and at school. The intervention program was provided in groups of two to five children at the same time. Services provided on a group level were course days for parents, teachers, and children, respectively. This was combined with individual meetings and support for each child. Figure 1 gives an overview of the three steps included in the gaze-based AT intervention. All children, regardless of earlier AT experiences, were provided with the same service in the intervention program. Step 1 started with an introduction lasting two days, which consisted of education (how to create pages, make adaptations to the software, and handle the gaze-based AT) for stakeholders (e.g., parents, teachers, and assistants). Furthermore, the introduction included initial adaptation of the software in the gaze-based AT, and training for the child in how to gaze control and use the AT. For the three children that already had access to gaze-based AT at baseline the software was revised to match their abilities and needs. At the planning meeting (step 1) each child's prerequisites (e.g., gaze control skills, communication) and motivation for activities were on the agenda. Furthermore, prioritized participatory problems were identified (e.g., not being able to comment or answer questions during circle time in school), goals for gaze-based AT usage in daily activities were collaboratively formulated, and gaze-based AT strategies developed. After the planning meeting a goal planning document was established by the MPC team to ensure a shared focus on the goals. The course days for teachers and parents (parents meeting parents; teachers meeting teachers) (steps 2 and 3) involved the exchange of experiences of the children's gaze-based AT use in daily activities at home/in school, demonstration of pages in the software for different activities by the MPC team, and further adaptation of the gaze-based AT for each child's needs. During the course day for children (step 3), children played games and music together by using their gaze-based AT to gain positive experiences from the use and to practice how to use the gaze-based AT. The individual planning and follow-up meetings (steps 1–3) were provided for all stakeholders for each child (parents, teacher, assistants, local services such as members from the AT center and the local pediatric rehabilitation team, in total 5–14 individuals for each child). During the follow-up meetings, the goals were evaluated, and strategies adapted if needed (steps 2–3). In all steps, individual support was provided when needed, for five occasions for each child. It consisted of home or/and school visits by members of the MPC team to provide direct or indirect support to the child, parents and/or teacher, and assistants, such as in adaptation of the software, in the usage of gaze-based AT in daily activities, and support with gaze control.

Outcome measurements

Computer usage diaries

Through direct observation by parents, teachers, or assistants, usage of gaze-based AT was measured in a computer use diary:[38] one concerning the daily usage in school and the other one the daily usage at home. Each day the following were noted: 1) *type of computer activities per day* noted by one or more of the predefined activities, with the possibility to add activities. For example, in school there were 10 predefined activities (e.g., to make presentations or to talk with someone), and 2) *duration of use for each activity per day (in minutes)* with individual responses estimated after each activity throughout the day.

Goal attainment scaling

To formulate and evaluate the goals of meaningful use in school and at home with gaze-based AT, the Goal Attainment Scaling, GAS,[39] was used. The instrument has a five-point scale, from −2 (starting level) to +2 (more than expected) with zero as the expected level of success. Each goal is described with five levels including somewhat more (+1) and somewhat less (−1) than expected, and much more (+2) and much less (−2) than expected in relation to the expected outcome (0).[39] The instruction was to set −2 as the current individual level at baseline. GAS has shown good

responsiveness in detecting clinically relevant change[40,41] and content validity according to determining goals that represent important progress.[42]

The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0)

Quest 2.0[43] was used to evaluate parents' satisfaction with the gaze-based AT as an assistive device and with the service provided related to the gaze-based AT. The instrument included eight satisfaction items concerning the device (e.g., ease in adjusting, easy to use) and four items concerning the service (e.g., professional services, follow-up services, repairs and servicing). The instrument includes the same question for each item: "How satisfied are you with..?" (e.g., professional services). All items had five graduations (1–5) from "Not satisfied at all" to "Very satisfied". Mean scores were calculated for rated items corresponding to the device scale, the service scale, and all items together (Total scale). Higher values represent higher satisfaction. The instrument has shown good test-retest stability (0.82–0.91), good interval consistency, and validity.[43]

Procedure

Table 2 shows the time points and measurements for data collection. At baseline, the research group met the parents at the RPC and they were provided with information about the study. During baseline, parents and teachers observed and documented the child's use of the computer as AT (gaze-based AT or, e.g., head-controlled mouse or switch) each day for a 14-day period in the home diary and school diary. The period that followed after baseline children participated in gaze-based AT intervention together with their parents and teachers. Eight children used their gaze-based AT at home and at school, and two children either at school (7) or at home (1).

During the intervention, the GAS was administered by the MPC team at the planning meeting, and subsequently the research team checked goals so that they were measurable and relevant. The MPC team was well-trained in using GAS collaboratively together with other parents and teachers since several years before start of this study.

At the time point "during intervention" (DI), computer diaries were posted to parents and teachers. They observed and noted the children's use of gaze-based AT each day during the 14-day period in the home diary (14 days) and school diary (10 days). All were contacted by phone so parents and teachers were able to ask questions about the diaries. Goals were evaluated at the first and second follow-up meeting as part of the gaze-based AT intervention. The intervention lasted between 9 and 10 months for all.

At post-intervention and at follow-up, the computer diary and Quest 2.0 were posted to parents, and the computer diary to teachers. Computer diaries were again filled in each day during a 14-day period and Quest 2.0 was completed by parents. At follow-up, parents were instructed to think of the period between post-intervention and follow-up when rating three of the items (professional service, follow-up, repairs and servicing) in the service dimension in Quest 2.0.

Medical records showed hospital stays with operations, or sickness periods for two children (2, 5) which caused them to be absent from school/preschool for at least 2 months during the intervention period. One of these children developed a severe form of therapy-resistant epilepsy during the study (2). Two children changed school (3) or assistants (2, 3) during the intervention. No concurrent interventions, such as medical treatments or other professional services that may have a potential positive influence on children's use of gaze-based AT, were monitored during the study.

Data analyses

The repertoire of activities was calculated by counting all activities, documented in home and school diaries, for each time point. The variables in computer diaries were calculated in each phase (each 14-day period), for home and school together, as follows: (a) *number of activities/day*, (b) *duration of usage* (min/day), and (c) *percentage of user days* (%), referring to the number of days with usage from the total number of days noted. In addition, the percentage of user days (%) was calculated for each activity in each diary (school and home diaries, respectively) for baseline and follow-up. Diaries were returned with 25 missing days in total in both the school and home diaries (B_1: 18 days, B_2: 7 days) out of 420 days in the diaries. Three new activities were filled in as individual responses under "type of activities" and these were included as separate activities (to choose activities, to participate in circle time in school, to look at the schedule to be informed of the day's activities).

To determine if there were any improvements between phases (A, B_1, B_2) in the computer use variables, the data were presented as graphs (number of activities/day, duration, % of user days) to be visually inspected regarding change of data pattern across phases, such as change between phases and trends within phases.

Formulated goals with GAS were evaluated for each child, and categorized to describe their content. Concerning Quest 2.0, median values and inter-quartile range were calculated on a group level for the device scale, service scale, and the total scale. To examine on an item level in Quest 2.0[44] was parents' scoring for each item

Table 2. Instruments for data collection.

Data collection	Baseline (A)	During intervention (DI)	Post-intervention (B_1)	Follow-up (B_2)
Computer diary home	14 days		14 days	14 days
Computer diary school	14 days		14 days	14 days
Goal Attainment Scaling	X	X	X	
Quest 2.0			X	X

grouped in being satisfied (4 "quite satisfied" and 5 "very satisfied"), and being less satisfied (1 "not satisfied at all", 2 "not very satisfied", and 3 "more or less satisfied").

Ethical considerations

On behalf of the children, written informed consent was obtained from both parents of each child participating in the study. The parents and teachers were informed that they could withdraw from the study at any time, without affecting the services given to them or the children in the gaze-based AT intervention. The study received ethical approval from the Regional Ethical Review Board in Uppsala, Sweden (2010/316).

Results

Repertoire of computer activities in home and in school

As shown in Table 3, all 10 children performed computer activities at home and/or in school at follow-up, whereas only five of the children (5, 6, 8–10) did so at baseline. Seven children increased the repertoire of activities from baseline to follow-up. On a group level, the mean value increased from baseline (mean = 1.8) to follow-up (mean = 3.8).

At follow-up, the computer activity most children performed was to talk with someone, in school (3–4, 6–10), as well as at home (2, 4–6, 9–10). However, it was only for the two oldest children (9–10) that this was the most frequently performed activity across the days (21–71%) at home, whereas the six youngest children (1–6) most frequently performed

Table 3. Computer activities children performed in home and at school.

Child		Baseline (% of days*)	Follow-up (% of days*)
1	*Home*	–	Play (43), music# (43), photos** (14)
	Number of activities	0	3
2	*Home*	–	Play & games (50), music# (14), photos** (28) Talk with someone (14)
	School	–	–
	Number of activities	0	4
3	*Home*	–	Photos** (28)
	School	–	Circle time£ (83) Talk with someone (83) Make presentations (50)
	Number of activities	0	4
4	*Home*	–	Play & games (50), music (71), photos** (71) Talk with someone (71) Counting (36)
	School	–	Talk with someone (70) Skill training (40) Counting (10)
	Number of activities	0	6
5	*Home*	Play & games (36), photos** (14) Talk with someone (21)	Play & games (50) Talk with someone (28)
	School	Circle time£ (10) Counting (60)	Play & games (20) Skill training (40) Counting (20)
	Number of activities	5	4
6	*Home*	Play & games (28) Photos** (28)	Play & games (21), music# (21), photos** (21) Talk with someone (21)
	School	Skill training (90)	Skill training (100) Talk with someone (25) Play & games (12), music# (62)
	Number of activities	3	5
7	*School*	–	Talk with someone (20)
	Number of activities	0	1
8	*Home*	–	–
	School	Talk with someone (78) Schedule for today (78)	Talk with someone (88)
	Number of activities	2	1
9	*Home*	Talk with someone (21) Write with symbols (21) Play & games (21), music# (21) Counting (7)	Talk with someone (21) Writing with symbols (14)
	School	Write with symbols (20) Skill training (60) Search information on Internet (10) Counting (20)	Talk with someone (44) Skill training (44) Search information on internet (33) Play & games (11)
	Number of activities	7	5
10	*Home*	–	Talk with someone (71) Music# (21)
	School	Skill training (44)	Talk with someone (100) Skill training (100) Make presentations (83) Circle time (33)
	Number of activities	1	5
Range of activities		0–7	1–6
Mean (median)		1.8 (0.5)	3.8 (4)

* % of days performing each computer activity in school (of maximum of 10 days) and at home (of maximum of 14 days), ** looking at photos, # listening to music, £participating in circle time in school.

activities such as playing games, watching photos, or listening to music across the days at home (14–71%).

Change in number of computer activities and duration of use

Figures 3a and b show graphic presentations of data on the number of performed computer activities per day and duration of computer activities (min/day) over time. Visual inspection of the data show an overall positive effect post-intervention (B_1) that was maintained at follow-up (B_2) for *Emma, Jacob, Daniel, Max, Isaac, David*, and *Anna* in both the number of performed activities and in duration of use (see Figure 3a and b). Six of these children's data show a distinct positive change over time, whereas David's data show a pattern with a small positive change over time. On the other hand, as shown in Figure 3b, the data of *Adam, Lucas*, and *Marcus* show no effect at B_2, although one of these children, *Lucas*, had a small positive effect at B_1 in both number of activities and duration of use. When inspecting the trends within phases, increasing trends were found within B_1 for both duration of use and number of computer activities for three children (Emma, Jacob, Anna). Within phase B_2, decreasing

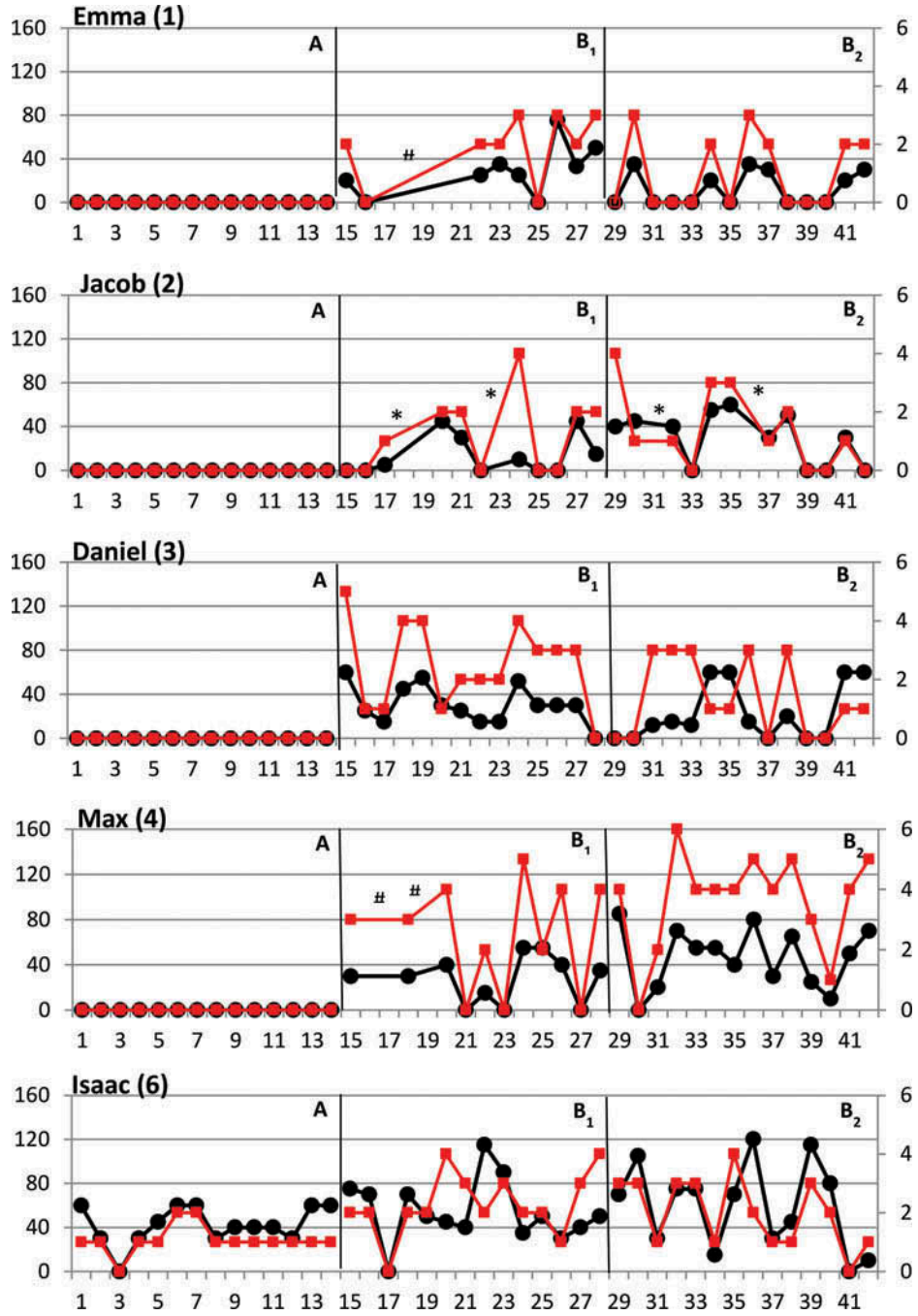

Figure 3a. Five of the children with positive change from baseline (A) to post-intervention (B1) and with maintained effect at follow-up (B2), in duration of computer use (black line) and in number of computer activities (red line). Missing days: # due to broken gaze-based AT, * due to that the child was sick.

Primary Y-axis: minutes; secondary Y-axis: number of activities. *Black line:* duration of computer use. *Red line:* number of computer activities.

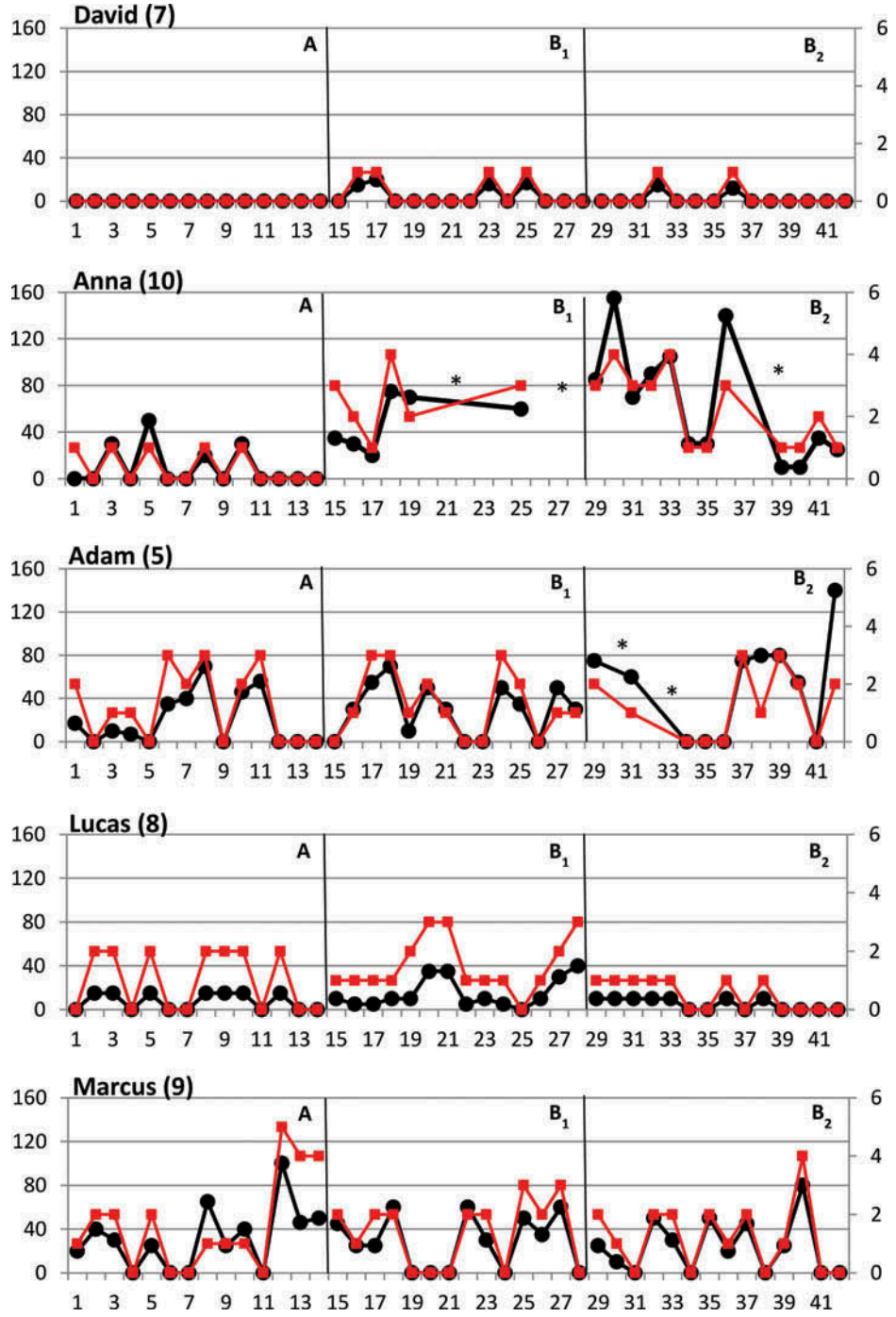

Figure 3b. Two of the children with positive change from baseline (A) to post-intervention (B1) and with maintained effect at follow-up (B2) (7, 10), and three children with no effect over time (5, 8, 9), in duration of computer use (black line), and in the number of computer activities (red line). * Missing days due to that the child was sick.

Primary Y-axis: minutes; secondary Y-axis: number of activities. *Black line:* duration of computer use. *Red line:* number of computer activities.

trends were found in number of computer activities (Emma, Jacob, Daniel, Anna) and in duration of use (Jacob, Max, Anna).

Change in percentage of days

As shown in Figure 4, seven children both increased in percentage of days from A to B_1, and maintained a positive change from A to B_2 (1–5, 7, 10), even though some children decreased at B_2 compared to B_1 (1, 3, 5, 7). From A to B_2, the three remaining children had no change or a decreased percentage of days over time. *Isaac* (6) already had a high percentage of days at A, and maintained this level with no change over time. *Marcus* (9) decreased in percentage of days over time, and *Lucas* (8) did not maintain the increased percentage of days from B_1 to B_2.

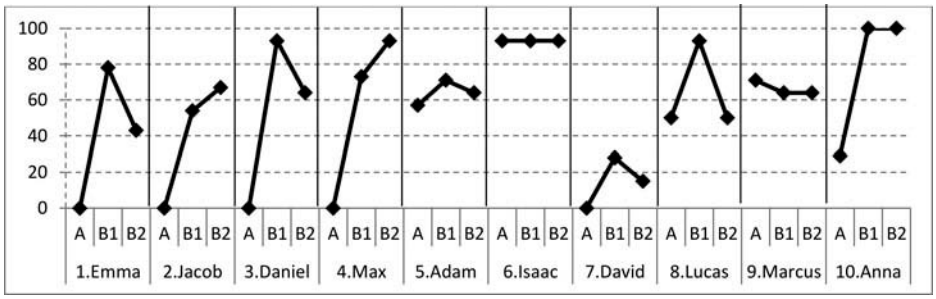

Figure 4. Percentage of days with computer use (%) over time for each child. Three children used a gaze-based AT at baseline (6, 8, 9), one child a head-controlled mouse (5), and one child a switch (10).

Goal attainment

A total of 58 goals were formulated at baseline for the 10 children (mean = 6 goals, median = 6 goals, range 3–9 goals/child), for gaze-based AT usage in school (37 goals), and/or at home (21 goals). The formulated goals considered using the gaze-based AT to communicate with others (20 goals), to interact with others (seven goals), learning to use and regular usage of the gaze-based AT (13 goals), to make choices (12 goals), and to do school tasks (six goals). Achieved goals are shown in Table 4.

All children attained goals, and the number of attained goals (scoring zero or higher) increased over time, with 55% attaining goals during the intervention (32/58), and 60% post-intervention (35/58). Post-intervention, 22 goals were attained in school (22/37) and 13 goals at home (13/21). Eight children

Table 4. Description of attained goals for each child.

	Achieved goals*		Context for goals	Description of achieved goals	
Child (age in years)	During intervention	After intervention	Home (H), School (S)	(Post-intervention)	Topic of goals
1. Emma (1)	3/4	4/4	H	To interact with sibling or parent during play activities	Interact
			H	Naming objects	Communicate
			H	Usage at home over 5 days/week	Regular usage
			H	Find different pages in the gaze-based AT independently	Learn computer use
2. Jacob (5)	3/9	2/9	H	Express opinions through the communication pages at home	Communicate
			H	To interact with siblings/parents in an arranged play activity	Interact
3. Daniel (6)	1/3	3/3	H	Use the gaze-based AT on a regular basis at home (weekend)	Regular usage
			S	Choose activities every day in school (2 times/day)	Make choices
			S	Interact with children in play activities in school	Interact
4. Max (6)	4/6	3/6	H	Usage on a regular basis at home (2–3 times/week)	Regular usage
			S	To answer questions during circle time in school	Communicate
			S	Interacting with an adult in an arranged school activity	Interact
5. Adam (8)	1/7	1/7	S	Arithmetic in school	Perform school tasks
6. Isaac (8)	5/6	6/6	S	Interacting with classmates, e.g. in play situations	Interact
			S	Answer a question about how he feels in school	Communicate
			S	Playing music to classmates (2 times/week)	Perform school tasks
			S	To choose song during circle time	Make choices
			H	Choose what to do at home every weekend	Make choices
			S	To choose recess activity in school (2 times/week)	Make choices
7. David (9)	4/4	4/4	S	Usage on a regular basis in school (3 days/week)	Regular usage
			S	Usage of an increased number of pages in the gaze-based AT	Learn computer use
			S	Interaction with a classmate occurs during activities with the gaze-based AT	Interact
			S	Use eye control in a conscious way	Learn computer use
8. Lucas (13)	6/8	6/8	H	Regular usage at home (every weekend)	Regular usage
			S	Answer a question about how he is doing at school	Communicate
			S	Talk about something that happened at home	Communicate
			S	Talk about what he has been up to during the weekend	Communicate
			H	Talk about something that happened in school	Communicate
			S	Choose recess activity in school	Make choices
9. Marcus (15)	2/6	3/6	S	Say what he wants to do during recess in school	Communicate
			S	Usage during Swedish lessons	Perform school tasks
			H	Use at home for self-selected leisure activities (3–5 times/week)	Regular usage
10. Anna (15)	3/5	3/5	H	Choose activity every weekend at home	Make choices
			S	Explore and use the pages in the gaze-based AT in school (every school day)	Learn computer use
			S	During circle time, say what fruit she has brought with her to school	Communicate

attained between half of the goals to all goals post-intervention, whereas two children attained less than half of the goals (2, 5) (see Table 4). Each child with unattained goals (six children, 23 goals) had at least one goal (1–4 goals) that showed progress post-intervention (14 goals scoring −1). Three children had unattained goals only in school (4–6). Unattained goals with no change as well as with progress were found in all different areas of use (communication, interaction, regular use, choices, and school tasks).

Satisfaction of gaze-based AT and services

Post-intervention the parents gave a high satisfaction rating for the gaze-based AT (Device median: 3.9, q1–q3: 3.4–4.2) and for the service delivery (median: 4.3, q1–q3: 4.3–4.4). At post-intervention the median value of the total scale was 4.0 (q1–q3: 3.7–4.2). The parents gave a somewhat lower satisfaction at follow-up (Device: median, 3.4; q1–q3: 3.0–4.1; Service median 3.1, q1–q3: 2.8–4.3; Total scale median 3.5, q1–q3: 3.0–3.9). On an item level for the eight Device items most parents (6/10 to 8/10) were satisfied (scoring 4 or 5) at post-intervention with all items except for the items durability (5/10) and comfort (5/10). At follow-up most parents (6/10 or 7/10) were still satisfied with four out of eight Device items (dimensions, safety, ease of use, and effectiveness). Concerning the four Service items, a majority of the parents were satisfied with all items at post-intervention (B_1) while a majority were satisfied only with professional services at follow-up (B_2) as follows: service delivery (B_1 8/10; B_2, 5/10), repairs & services (B_1: 10/10; B_2 4/10), professional services (B_1: 9/10; B_2 6/10), and follow-up services (B_1 9/10; B_2 3/10). At time point for follow-up the three most important items identified were as ease of use (7/10), effectiveness (6/10), and follow-up (3/10).

Discussion

This study shows that children with a severe physical impairment without speaking ability can increase their repertoire of doable computer activities with a gaze-based AT. Seven children, of different ages, increased the number of performed computer activities from baseline to follow-up. Thus, these results were consistent even after withdrawal of services related to the gaze-based AT intervention. Research indicates that children with the most severe motor impairments (GMFCS IV or V) are those that have the lowest level of participation in activities,[45,46] and are therefore the ones most likely to need a computer to be able to perform activities. Research indicates that these children need a high level of support from others to participate in activities.[10,23] Among children with such profound impairments, every computer activity that expands the repertoire of doable activities may therefore be a significant contribution for the specific child to explore childhood activities. In the present study, the MPC team collaborated with parents and teachers to promote the implementation of gaze-based AT in daily activities. The need for collaboration between professionals and parents and teachers has been highlighted by previous research,[16] which found that absence of guidance to parents and teachers in how to expand the repertoire of activities with the gaze-based AT led to a limited repertoire of doable activities for the children.

The visual analysis of data shows that post-intervention, eight children increased their computer usage either regarding the number of performed activities per day, time spent performing activities per day, and/or the percentage of days with gaze-based AT use, and the effect was maintained at follow-up. However, due to the nonexperimental design the internal validity may be compromised in this study[47] and the results with increased computer usage over time therefore need to be interpreted carefully.

The results also reveal that all children achieved goals with the use of gaze-based AT, and eight children completed between half to all of the goals. The completeness of goals thereby shows the effectiveness of gaze-based AT and how it differed among the children themselves. A reason for unattained goals could be that the children did not formulate the goals due to their communication difficulties. Although the children's motivation for specific activities was considered by adults, unattained goals may be due to the lack of or decreased motivation from the child to perform a certain activity. Another reason for unattained goals might be that too many goals were formulated at a time. Most children achieved three to four goals, which might be a reasonable number to work with at a time. At least three goals are recommended for the GAS.[39] However, as the gaze-based AT was implemented in two settings at the same time (school and home), several goals were formulated for each setting. The results indicate that when formulating goals both for home and for school, everyone involved needs to be aware that too many goals might be set. Another explanation for unattained goals is special events, such as sickness periods, that may have hindered the achievement of goals for the two children that achieved less than half of the goals (children 2 and 5).

The results show that children mostly used the gaze-based AT for up to 1 hour per user day. However, it remains unknown whether the children in the present study were satisfied with the amount of usage, or whether they would have liked to perform more activities or spend more time using the gaze-based AT. The AT usage will be determined by the interplay between the child, the activity, the AT, and the specific environment.[26] Although these children with a gaze-based AT can perform activities without support from others, they will still be dependent on a supportive environment for setting up the system and positioning the child at the computer, after which they will be free to explore computer activities.

The current study confirms the need of longitudinal measures of the use and usability of AT to understand its effect in daily activities, as suggested in the literature.[30] Although children maintained a positive change at follow-up compared to baseline, the results also demonstrate that for some children there were decreased changes between post-intervention and follow-up. This result indicates a need for recurring support to maintain a high level of long-term use. In addition to ongoing technical support, children, parents, and teachers will need follow-up services to continue to adapt the gaze-based AT to the children's changing needs and accommodate their development. Based on the current study's results, a recommendation is to offer follow-up services (e.g., one or

two days), from an MPC team once a year after the gaze-based AT intervention, to promote sustained high use of the gaze-based AT.

The results indicate high satisfaction of parents with the gaze-based AT, and with services related to the gaze-based AT intervention. High satisfaction with the AT is in line with results from a survey study among adults with severe physical impairments using gaze-based AT in daily life.[32] On the other hand, in contrast to the current study's finding, dissatisfaction with professional services has been found among parents of children with physical impairments using different ATs.[18,20] In addition, a survey study of adult users of AT found low satisfaction to be related to the abandonment of AT.[48] Therefore, the high satisfaction both with the gaze-based AT and with the services among parents found in this study at post-intervention might be a prerequisite for the results with sustained use of gaze-based AT over time. Nevertheless, a majority of parents were satisfied with all services at the end of gaze-based AT intervention, but only with the professional services at follow-up. For example, the results show that few parents were satisfied with the technical support and follow-up services for the period from the end of gaze-based AT intervention to the time point for follow-up. It would be interesting to further investigate in a future study what made these changes. Measuring parents' satisfaction is important, as they are the ones that primarily implement interventions in the families' routines and daily life for children with impairments.[24]

The present study indicates that the gaze-based AT intervention supported use of gaze-based AT over time, after withdrawal of services related to the gaze-based AT intervention. It appears that the intervention program empowered parents and teachers to support the child in the use of AT with less support from professionals over time. This finding is in line with research that indicates that involving key persons in decision-making and goal formulation and empowering key persons with knowledge and skills needed (e.g., handling technology, adapting the content, supporting the child in the use) are necessary to achieve sustained use of AT over time.[16,19,24,49,50] As pointed out by previous research,[51] to achieve good outcomes for students with severe impairments, extended time is needed as well as opportunities to develop mutual understanding and joint efforts among multiple key persons.

The current study suggests that introducing gaze-based AT in daily activities together with receiving the services spread out during a time period of 10 months is related to the goal achievement of gaze-based AT usage for nonspeaking children with severe physical impairments. More goals were also achieved at 9–10 months after the start of the intervention program, than at 5 months. Several children had health-related issues during the gaze-based AT intervention, which is common in this child group.[52] Therefore, the time frame needs to allow for these extraordinary events during the implementation of the gaze-based AT in daily activities. In addition, case studies suggest that gaze-based AT needs to be implemented over an extended time to maintain motivation and interest for individuals with profound impairments.[14] Such a time frame also allows the content in the communication pages in gaze-based AT to be gradually increased over time in response to the changing needs and abilities of the user.[14]

The service in the gaze-based AT intervention is based on several interacting key elements (increase knowledge, collaboration between key persons, child's preferences for usage, and goal setting). Whether some key elements are more influential than others in maintained use of gaze-based AT cannot be concluded from this study. Nevertheless, previous research indicates these key elements to be of significance in intervention studies with children with physical impairments.[38,51,53]

A strength of this study is its daily measures of gaze-based AT usage over 14-day periods, which allowed any fluctuations in usage during each of these periods to be tracked. A limitation of the study is that only 10 children participated and therefore the results need to be interpreted carefully. Representing a small group of children, all children that were referred to one regional pediatric center in Sweden over a period of 3 years were included in this study. However, a larger group of children might have revealed a more varied use of the gaze-based AT after the gaze-based AT intervention. The limited information of children's cognitive level is also a limitation in the study. Assessing cognitive level in children with both severe motor and communicative impairment is difficult due to their restricted ability to participate in a standardized assessment situation.[54] Notwithstanding, population-based studies show that cognitive impairment correlates with the severity of motor impairment[5] and is more common among children with low functional level in communication,[55] such as in the present study.

The responsiveness of GAS depends on the professionals' knowledge in selecting goals and levels representing important change.[40,56] The MPC team in this study was educated in using GAS. In addition, research team also checked goals for relevance and measurability. A potential response bias is that the computer use diaries with estimations of gaze-based AT usage were filled in by parents, teachers, and assistants. It is known that familiar partners may have a tendency to present a more favorable image of a situation,[47] such as overestimation of the duration of gaze-based AT usage due to expectations. This needs to be considered when interpreting the results. To reduce the recall bias, they were instructed to note the minutes of use directly after each activity throughout each day. Furthermore, none of the researchers, parents, teachers, or assistants involved in measuring outcomes was blind to the intervention. Blinding to type of AT is not possible if the purpose is to observe AT usage. Due to ethical considerations blinding to receiving service or not is difficult. For example, it cannot be recommended to give service only to some of the children who are provided with gaze-based AT.

The results in this study are based upon measurements. The study does not include qualitative information from parents or teachers on functional changes and experiences of gaze-based AT usage in daily life. Parents' and teachers' experiences will be reported in two forthcoming studies.

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Declaration of interest

The authors report no conflicts of interest.

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