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Use of App-Based and Voice-Guided Techniques to Increase a Concentration of Children with Autism Spectrum Disorder

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ABSTRACT

The main objectives were to investigate the potential benefit of an FM system for attentively and learning concentration of children with autism spectrum disoder (ASD). Three groups of participants were involved in this study: children diagnosed with ASD, aged from 9 to 12 years (N=16); parents (N=16); teachers (N=5). Four personal FM systems and a custom drawing app were used. Two simple tasks were performed: to outline the shape and to color the object. This had to be done with and without the FM system. The response time and the task completion time were captured automatically. Additionaly the effectiveness of technical measures was evaluated by teachers and parents by filling in questionnaires. With the FM system children performed tasks significantly faster than without them ($p = 0.008$, $d = 0.43$). Teachers (87.5%) estimated that children using the FM system had increased eye contact in daily activities. Further, parents (56.25%) noticed that after using the FM system, the child became more open to communication, and feels better in unknown environments. The application of voice-guided system can serve as an effective tool for addressing children's attention and learning concentration problems. However, an individualized approach is necessary to determine the benefit of the system for a particular participant.

Abbreviations: ASD: Autism Spectrum Disorder; ADHD: Attention-Deficit/Hyperactivity Disorder; HAT: Hearing Assistance Technology; FM: Frequency Modulation

Introduction

Autism spectrum disorder (ASD) affects children's lives and their development while ninterfering with their ability to communicate and interact with other children and adults [1]. This not only influences their home life but also can be particularly challenging when it comes to their success in school, especially in noisy environments such as classrooms [1-5]. Children with ASD can become passive and struggle to keep a focus on auditory stimuli like the voice of the teacher [6]. Limited abilities in self-regulating emotional and behavioural feedback may also affect their educational advance [7,8]. Children with tactile sensitivity

are more likely to be inattentive and distractible in the classroom. Interventions that reduce unpredictable tactile input need further exploration and new tools [9]. One of such sensory deprivation tools might be a frequency modulation (FM) system. The first study with using of wireless listening technology in children with autism was proposed by Rance et al. [4]. The results showed that the children heard and communicated better using wireless technology.

The research indicates that FM systems are the most common assistive listening devices used in classrooms by students with hearing loss. The benefits provided by these devices have resulted in an expansion of their application to extend beyond individuals with severe-to-profound hearing loss to individuals with minimal, conductive, and fluctuating hearing loss, as well as individuals with normal hearing who have additional learning problems. All these advantages were studied and scientifically justified [10-15]. A technological approach of FM that scientific studies have proven can help children with ASD to concentrate better on the speaker's words. The use of an FM system is not a form of therapy; it is merely a technology that makes it easier for a child to focus on what is being said. Phonak Field Study News announced that their testing showed that children who wore frequency modulation (FM) system had improved their speech understanding by an average of 53% compared to children who did not wear the technology [16].

Furthermore, several studies have reported that FM systems help achieve improving speech perception and speech recognition by 17% [4]; augment children's attentiveness, awareness and demeanour [4]; and boost listening and concentration abilities [17]. Latter abilities have been identified as the most significant factors affecting academic performance [9]. Only handful of studies of the advantages of non-traditional use of FM systems for children with ASD have been published and reported promising results after using the FM system in decreasing withdrawal and improved behaviour in the children [4,6,9,18,19]. In 2013, the study published by Schafer et al. [18] on the use of FM system for children with ASD and children with attention-deficit/hyperactivity disorder (ADHD) showed that the application of the FM system highly improved speech recognition. Sustained use of FM listening devices can enhance speech perception in a noisy environment, aid social interaction, and improve educational outcomes in children with ASD [4].

One of the most acceptable sensory deprivation measures for children with communication and social impairment, specifically ASD, are often used educational and recreational applications (apps) within the context of their home and school settings. An advantage of app-based learning by extending the learning environment was seen in many studies [4,20-27]. The present study uses both above-mentioned tools: FM system and an app. It is focused on improving concentration outcomes for children with ASD via app-based performance and social behaviour using the voice-guided system. The main objectives were to investigate the potential benefit of an FM system for attentively and concentration of children with ASD. The following research questions were addressed: the use of an FM system increases the concentration of the child and facilitate focus on specific tasks; eye contact is more frequent, and it is easier for the child to be interested and involved in activities.

Materials and Methods

Participants

The experiment was a part of the educational process at primary special schools. All procedures performed in studies involving human participants were in accordance with ethical standards and with the 1964 Helsinki Declaration as revised in 2000 (Ethical agreement R-I-002/350/2018). Teachers and parents were instructed and agreed to incorporate the technical tools we offer into their daily activities and subsequently evaluate the results. The consents of all participants were obtained. The first group of participants were 16 children (13 boys and 3 girls), diagnosed with ASD, aged from 9 to 12 years (mean age 10 ± 1.2 years) Inclusion criteria were: children should be 9 to 12 years of age, confirmed autism diagnosis; a hearing should be within normal limits. Children with ASD were excluded if they had an additional intellectual, hearing, visual, or physical impairment or were currently receiving occupational therapy to address sensory-processing issues. Children with cochlear implants, hearing aids, or other types of corrective hearing devices were not considered.

The second group were the parents of the children. Parents took the FM systems home and helped the child to get used to it as well as observed their child and evaluated his learning/concentration/communication outcomes. The third group consisted of 5 teachers who taught them on a daily basis. Teachers observed the children during the tasks with and without the FM system. They presented their observations and assessments in the survey responses. Both parents and teachers were trained to use the voice-guided system according to standardized conditions as well as how to instruct the child during the task performance with it and without.

Voice-Guided System

In our study, four Phonak (Sonova, Switzerland) personal FM systems consisting of behind-the-ear Roger Focus receiver together with Roger Pen microphone were used. It offers typically developing hearing children the ability to clearly hear and focus on all relevant speech information required for his or her development and learning. A recommended real-ear measure

for fitting Hearing Assistance Technology (HAT) on children with normal hearing was used. The FM system allows transmitting the teacher's/parent's voice directly into the child's ear at controllable volume. However, due to the increased tactile sensitivity, some children with ASD may not accept FM receivers. And we were ready for that. We got the kids used to the headphones slowly. During the study, the parameters of the FM receivers were set to the default values set by the manufacturer: audio signal output (out of the box) 68 dBA free-field equivalent (transmitter in compression, f_{mod} = 1 kHz, surrounding noise level <58 dB SPL (SPL – sound pressure level); volume range -8 dB to +8 dB; frequency range 100 Hz – 7.2 kHz. The examiners or parents through listening checks verified operation of the FM system before each trial.

Tablet and Drawing Application

Figure 1: Shape and colour options in the Drawing App.

Tablets and apps are willingly used by ASD children; therefore, it was involved in the study to design the unified and inclusive educational process. To ensure the same conditions for all participants in the study, the use of existing tablet applications was discarded. A custom new drawing app that could help formulate simple, well-understood tasks for children was created. In the app, one can choose the shape and colour; in fact, colour and shape are two very noticeable attributes of the world around us. Understanding colour and shape is recognized as a tool for learning many skills in life. Four shapes: circle, oval, triangle and square are available (Figure 1). Two simple tasks were designed: to outline the selected shape and to colour it. The response time (how fast the child reacted to the task he was given) and the task time (how fast a child performs a task) were captured automatically since the task was accomplished. Refusals to perform the task were also recorded.

Experimental Design and Procedure

The "before-after" experiment was designed (Figure 2). After children enrolment to the study, parents were introduced to app-based and voice-guided platform and asked to use FM system for 10 days at home and school as much and as long as it possible and in all activities of daily living. Parents helped kids to get used to the proposed tool, and completed a report to indicate how long the child used the app and FM system at home during the 10 days. Study tasks were included in children day-to-day learning environment as well. The children who participated in the study worked in their normal routine. And once they get used to the voice guided system the teacher worked with each of them individually. The children needed to perform two basic tasks on the tablet by listening to the teacher's instructions aloud and using the voice-guided system: outline selected geometric figure, and after colour it. During FM system usage in the class, children not only perform tasks but also communicate with teachers. To obtain the most accurate results of the study, it was conducted by the following conditions: the tasks were identical; tasks without the FM system (no FM) and with the FM system were performed at the same time of day during lessons while the children are still accustomed to working; the task was performed by children in their classroom, at their school desk; teachers were prepared to instruct kids during the tasks' performance in both conditions (no FM and FM) and encourage continuing and improving.

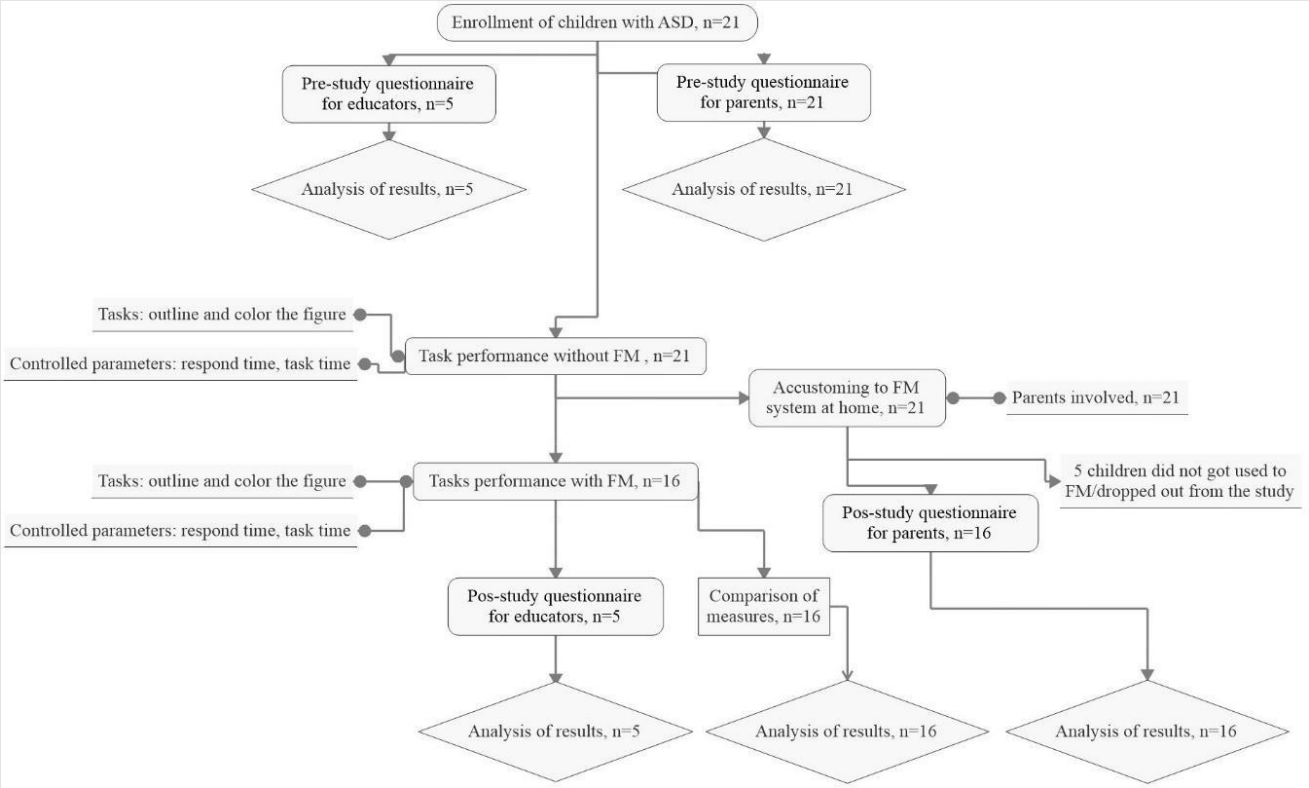

Figure 2: Experiment flow chart.

An app operation: first, the child must enter his name. If the child fails to do so, the teacher enters. Then the child can choose the colour. The teacher gives instructions: which figure he must choose, specifies to outline it as accurate and as quick as possible (Figure 3a). In the same order, the child is required to outline all 4 shapes - circle, ellipse, triangle and square. Upon completing this task, moving to the next - the colouring of the figures while leaving as little as possible white space (Figure 3b). The colouring area was captured. All the tasks performed under the teacher supervision and all the time instructing and encouraging. The response and task completing times were recorded automatically. The response time is the time measured from the moment when a child chooses a geometric shape to when it starts outlining or colouring it (depending on the task), from the first touch of the screen with his finger. Meanwhile, the task completing time begins from the first touch to the end of the task. Teachers were asked to complete the questionnaire composed according to the literature [18] about children concentration and communication. The first part of the questionnaire (pre-study) consisting of 8 questions was given to educators before they completed the study to find out the abilities and behaviour of children at school. The second part (4 questions) – post-study – after measures were completed. Parents were asked to complete the questionnaire of 9 main questions about the kid concentration and communication during FM system usage.

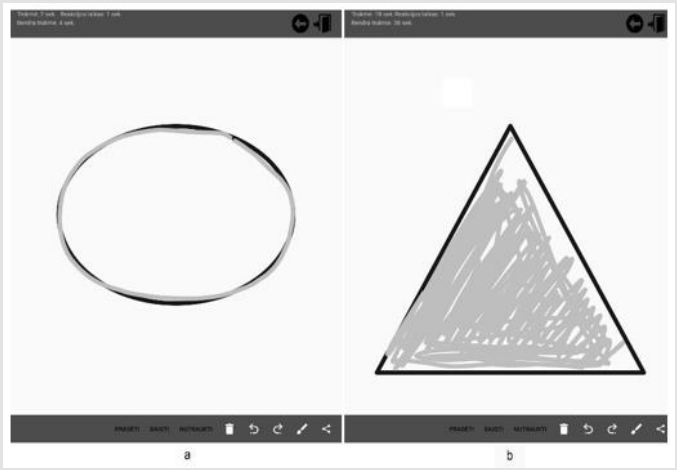

Figure 3: Tasks in the Drawing app:
a) To outline the shape;
b) To colour the shape.

Statistical Analysis

Collected data were analysed using Statistica 13.1 (StatSoft, USA)). The Lilliefors normality test ($p < 0.05$) was used to test data normality. The Cohen's value *d* was calculated to evaluate effect size of FM system: $d = 0.01$ - very small effect size, $d = 0.20$ - small effect size, $d = 0.50$ - medium effect, size, $d = 0.80$ - large effect size, $d = 1.20$ - very large effect size, $d = 2.00$ - huge effect size [27]. Normally distributed data were compared utilizing the parametric statistical method, i.e., one-way analysis of variance ANOVA (with significance level $\alpha=0.05$); data that were not normally distributed ($\alpha=0.05$) were compared by employing a non-parametric statistical method, i.e., Kruskal–Wallis test ($p<0.05$). With regard to the relationship between quantitative variables the normally distributed data are represented as mean ± SD, while the non-normally distributed data are represented by median.

Results

No specific characteristics were observed among the boys and girls involved in the study, so gender will not be considered when evaluating the results. The potential differences in the amount of the intervention that participants received were not statistically significant ($p>0.05$). Since the parents had agreed to perform the test anonymously, children' results were not marked by names and numbers.

Response time

The analysis of total measured response time (Figure 4) revealed a significant main effect of listening conditions (in the way of use FM systems and favouring the FM use) with $p = 0.000002$. The gain from the FM system yielded an effect size of $d = 0.372$. This effect is considered medium according to Cohen [29]. Analysis of on-task behaviour results presented in Table 1.

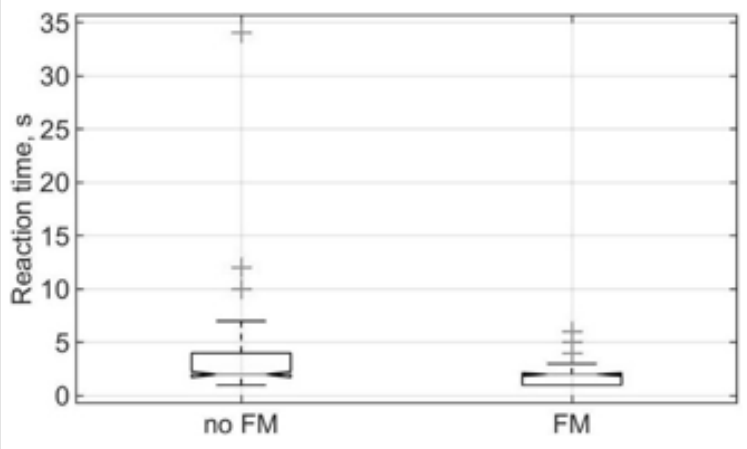

Figure 4: Total response time in different listening conditions no FM and FM.

Table 1: Response time, n = 16.

Task	Shape	Time, s		Effect (d)	P
		no FM	FM		
	circle	3.75±2.91	2.25±1.06	0.60	0.084
	ellipse	3.06±1.91	1.69±1.01	0.67	0.022*
	triangle	2.88±1.82	1.50±0.82	0.65	0.015*
	rectangle	2.88±1.41	1.88±0.81	0.71	0.025*
	circle	3.31±2.27	1.56±0.89	0.76	0.0038*
	ellipse	1.94±0.85	1.81±1.05	0.10	0.379
	triangle	1.88±1.31	1.94±1.34	0.03	1
	rectangle	4.43±8.07	1.93±1.29	0.31	0.290

Note: Values presented as means ±SD, *indicates significant differences ($p<0.05$).

Task time

Outlining and colouring of the shape are different tasks and were differently accepted by children with ASD. Each individual case might be analysed separately since they are seen as very different tasks. Thus, the variability of the results is very high. Trying to summarise results it was determined, that outlining task is shorter exercise compared to colouring and total performance time yielded meaningful benefit from using the FM system with $p = 0.0075$ (Figure 5). The magnitude of the benefit of the FM system yielded effect size $d = 0.43$, which was considered medium according to Cohen [27]. Colouring task required children to maintain attention longer. The results did not show a significant difference between performing no FM and FM exercise, it has been observed that, by inviting children to perform the task through the FM system, they focused on the task longer and covered the larger area. One participant refused to colour the figures when tasks were performed without the FM system. However, he performed the task using the FM system. Since there was no measured colouring time at no FM condition, it was not possible to compare results. Therefore, the Figure 6 represents only results of 15 participants' at colouring task.

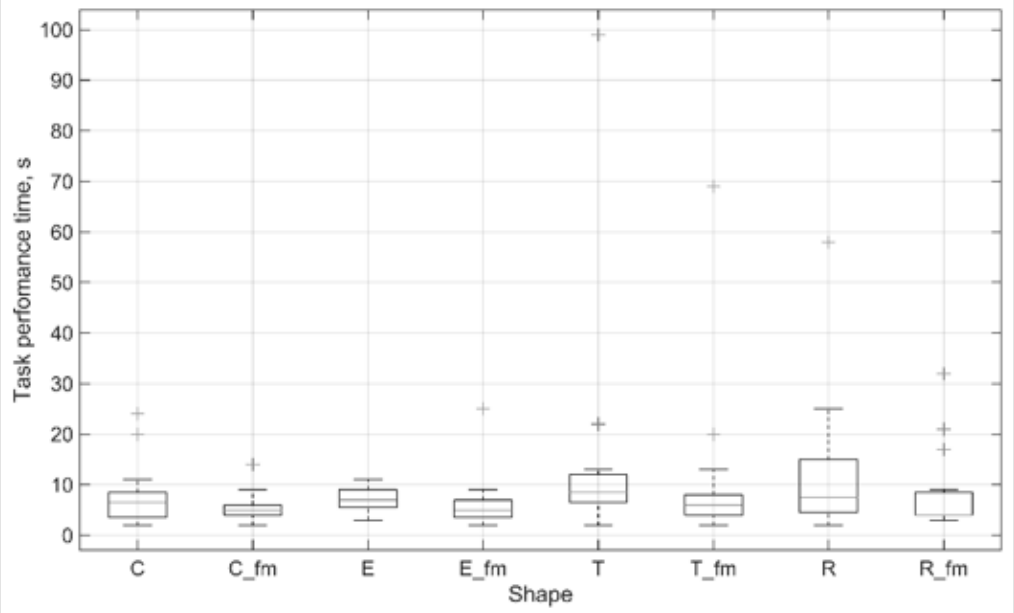

Figure 5: The time of outlining under different listening conditions, where C – circle, E – ellipse, T – triangle, R – rectangle.

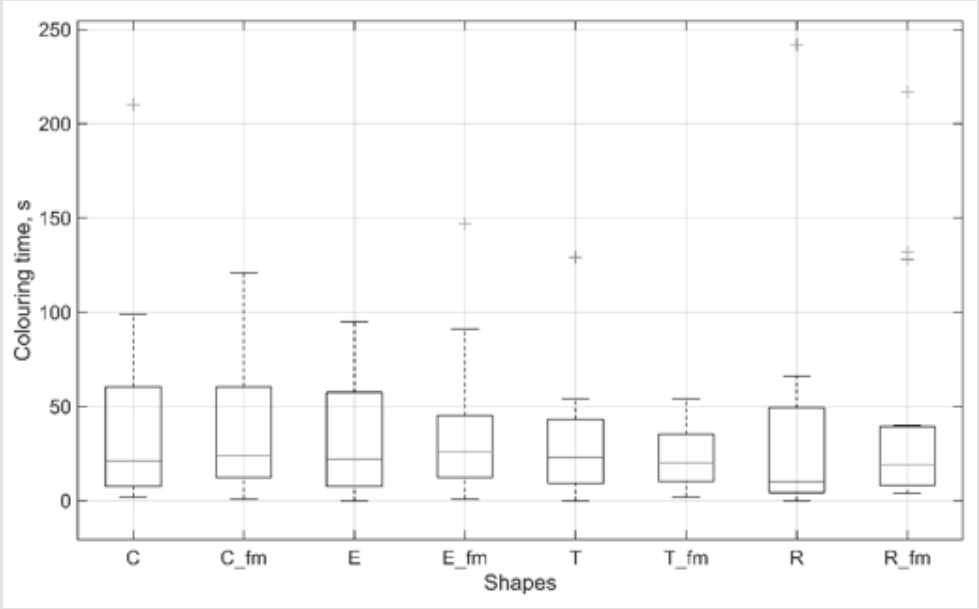

Figure 6: The time of colouring under different listening conditions, where C – circle, E – ellipse, T – triangle, R – rectangle.

Questionnaire

The first questionnaire was given to educators before the study to find out the abilities and behaviour of children at school. Pre-study questionnaire's results are displayed in Table 2. After the study was completed the questionnaire for educators had 4 main questions and results are presented in Table 3. The results show, that 87.5 % of teachers estimated that children using the FM system have increased eye contact in daily activities. They noted that it was easier to communicate with the child, who immediately drew attention to what the teacher was saying. When the child heard the teacher's words straight into the ear, he directed his attention to him, what allowed the teacher to communicate using emotions. It was much easier to get the child interested in doing a new task or leaving his comfort zone, for example, dare to go out to another class or yard. The nine questions questionnaire was given to the parents. Before the study, they answered three of the same questions as educators did (Table 2, No 1, 3 and 4). After investigation, they completed the same questionnaire plus two additional questions. All results are presented in Table 4.

Table 2: Pre-study questionnaire for educators, n=5.

No.	Question	Answer, %		
		Always	Sometimes	Never
1.	Does he/she maintain eye contact during a conversation?	37.5	25	37.5
2.	Is the child able to work in a group?	12.5	25	62.5
3.	Is it easier to talk with a child in silence than in a noisy environment?	50	50	0
4.	Is the child able to answer a question?	12.5	37,5	50
5.	Is the child able to listen to a teacher's task?	12.5	31,25	56.25
6.	Is the child able to concentrate and perform the tasks specified for him - colour, cut, etc.?	12.5	50	37.5
7.	What is the efficiency of a child's learning compared with peers in a classroom?	12.5	25	62.5
8.	What is the child's ability to focus on one task?	6.25	43.75	50

Note: *The values are given in sample percentage

Table 3: Post-study questionnaire for educators, n=5.

No.	Question	Answer, %		
		Always	Sometimes	Never
1.	Using the FM system, eye contact with the child has increased.	87.5	12.5	0
2.	Using the FM system, the child was calmer.	31.25	68.75	0
3.	Using the FM system, the child's concentration on work has increased.	75	0	25
4.	Using the FM system is easier to communicate.	62.5	0	37.5

Note: *The values are given in sample percentage

Table 4: Questionnaire for parents, n=16.

No.	Question	Answer, %		
		Yes	No	Sometimes
1.	Does he/she maintain eye contact during a conversation?	62.5	12.5	25
2.	Is it easier to talk with a child in silence than in a noisy environment?	62.5	37.5	0
3.	Is the child able to answer a question?	43.75	12.5	31.25
4.	Using the FM system, eye contact with the child has increased.	90	0	10
5.	Using the FM system, the child was calmer.	56.25	31.25	12.5
6.	Using the FM system, the child's concentration on work has increased.	68.75	31.25	0
7.	Using the FM system is easier to communicate.	68.75	0	31.25
8.	The "Focus" receiver has fallen from the ear.	0	75	25
9.	Would you like to continue the FM system test?	62.5	25	12.5

Note: *The values are given in sample percentage

For example, parents noticed that after using the FM system, the child became more open to communication. 56.25 % of parents noticed that children feel better in unknown environments; for example, in a grocery store the child was calmer, less stressful than ever when they used headphones and heard the voice of their parents. Total 68.75 % of parents were more satisfied that while using the voice-guided system it was much easier to communicate with the child. It seems that the child always listens and responds more often to the question or suggestion of doing household/ educational work.

Discussion

Before starting to discuss the results of the study, it is needed to go back and to make a note that five potential participants of this investigation have not accustomed to the FM receivers and dropped out. It turned out that the reasons for this were sensory disturbances. The FM receiver, which is worn on the ear, was accepted as a strong external stimulus; therefore, they simply pushed the receiver from the ear, even without having to turn it on. Previous studies also declare that children had tactile sensitivities to the receivers [4,18]. If it is desired to include sensitive children in programs or classes that deal with FM systems, first recommendations should be given to a company on possible modifications to the receiver design in response to children with ASD reactions and acceptance. Longer trials with FM system might diminish sensory disturbances of users. By compiling our research methodology and looking at the results of the investigations already done [9], we realized that the FM system alone will not be enough to increase the efficiency of the educational process and social skills of children with ASD. It is evident that a complex and balanced ,package of measures is required.

Teachers, parents, and the relevance of the tools used play an important role here [17]. We observed that it is very important the way of giving instructions during the task's ant the frequency of it. Children with ASD may be able to avoid complex visual input by averting the eyes or narrowing the focus of visual attention and to actively avoid sources of unpredictable tactile input. Environmental auditory input, however, is more difficult to escape. It is known that children with ASD willingly used various gadgets and learned some skills [24–26,28]. We also knew that there were many different software applications available [26], so we looked for the task environment and themes to be unseen and new to them. Our measured parameters partially confirmed our expectations. The response time in different listening conditions (no FM and FM) showed a meaningful benefit of FM systems use (p<0.05) with

medium effect size. We found out this reaction time was the most objective in the study. Subsequently, performing tasks children showed different patterns of behaviour with the FM system and without it.

For example, a child was asked to outline a shape without an FM system, in usual way and he thought for a long time knowing where to start a task, then he took a long time without hurrying, although he was all the time instructed to perform the task as accurately as possible and as quickly as possible. With the FM system, the task was performed faster because it was continuously and closely stimulated through the receiver to perform it. Therefore, it is not possible to judge the duration of a task as a consensus or concentration on a task. In addition, the results of task performance were not as expected. Summarized outlining time from all 16 participants showed FM system might be beneficial (p<0.05) with medium effect size d = 0.43. However, colouring time was difficult to analyse because of a large variation in the results and consequently, it did not show any significant difference in FM usage efficiency during performing a task. The different behaviour of children with ASD during a task was noted before [18]. Besides, we agree with the reflection that individual case should be considered during the educational process.

Therefore, the children did not really like this task and they needed to be instructed to do so all the time. Due to differences in methodology, it is hard to compare our measured parameters with the work of other researchers; however, we are reaching similar conclusions. Summing up, our study results suggest that the FM systems were helpful and might be beneficial for children with ASD like in previous works given results are suggesting [4,11,13,18]. However, it must be made very clear that the FM system itself is not the main child support. Parents and teachers must constantly motivate the children and help them to get involved. The results showed sensitive aspects of the study design and gave motivation for future works. The limitations of this work are relatively small sample size, nonhomogeneous experimental group. Further research needs to differentiate with what autistic spectrum disorder the FM system is most effective. One more group of participants would help to manage the results and interpret as well as to control the learning of repeated tasks and the influence of extraneous factors. The voice-guided systems should be additionally involved in the usual educational process and daily activities and compared with the preliminary results. Individual case analysis would help to find new patterns of behaviour during performing tasks.

Conclusion

After analysing the results and considering the opinion of teachers and parents, we conclude that the application of voice-guided system can serve as an effective tool for addressing children's attention and learning concentration problems. The FM system might be recommended for children with ASD: inability to use or very rarely keep eye contact; listening to the speaker only in a quiet environment; those with hyperactivity symptoms; children who rarely answer questions for incomprehensible reasons; having involuntary, recurring movements; not interested in concentrating on the work process. Summing up, our study results suggested that the app-based and the voice-guided platform was helpful and beneficial for most children; however, an individualized approach is necessary to determine the benefit of the voice-guided system for a particular participant.

Author Contributions

Conceptualization, K.D.; methodology, K.D. and J.P.; software, J.T.; formal analysis, K.D.; investigation, P.V.; resources, J.G. Z.D.A; data curation, P.V.; writing—original draft preparation, K.D.; writing—review and editing, J.G., J.P,.Z.D.A.; visualization, J.T, MC. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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