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Smart Pen - new multimodal computer control tool for graphomotorical therapy

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Abstract

Numerous researches indicate that dyslexia and dysgraphia are nowadays major problems in schools. Smart Pen is a tool for supporting the therapy of developmental dyslexia, with particular regard to dysgraphia. It comprises a display monitor equipped with a high-sensitivity touchpad and specially designed writing tool equipped with pressure sensors. The paper put emphasis on issues related to the design of the device and the development of software providing a vital part of the interface.

The software allows monitoring some interface parameters that are important from the therapy point of view, such as pen grip or time taken to complete an activity being a part of an exercise. The interface designed allows interesting (play and learn) activities to be performed with kids (i.e. learning of proper handling writing tools, basic writing etc).

Tests have been carried out to verify usability of the Smart Pen. The test results showed that children and therapists are keen on using the new tool. Furthermore, using Smart Pen it is possible to distinguish children without writing problems from those who have some motoric disruptions. A description of the tests carried out and of their results is included in the paper.

Keywords

developmental dyslexia, dysgraphia, multimodal interface

1. Introduction

There are many different definitions of dyslexia (called also developmental dyslexia), each of them focuses on discrete disturbance. Only one factor remains unchanged: dyslexia is a weakness in reading and in spelling. Researchers are still inconsistent what causes dyslexia. The most popular hypotheses indicate phonological or visual processing deficits, automacity impairments, central executive control dysfunction [7] [12] [15]. All this hypotheses do not exclude each other and therapists often agree that dyslexia is caused by many factors.

Since dyslexia has various symptoms, it can be divided into four groups [14]:

- dyslexia (in a narrower meaning) – problems with reading, also difficulties with words recognition, spelling and reading for understanding;
- dysgraphia – difficulties with hand writing; writing is distorted or illegible;
- dyscalculia – difficulties in understanding how to operate using numbers;
- dysortography – problems with writing according to orthographic rules in spite of knowing the rules.

The dyslexia is often explained by disturbances of visual, auditory, kinesthetic-motor, lateralization and spatial orientation analyzers. In this way it is easy to divide all dyslexia symptoms into groups. This division will also facilitate the identification of problems, which the proposed Smart Pen is designed to solve. In fact, only disturbances of the auditory analyzer are beyond capabilities of the interface. In contrast, the interface might be the best solution in case of dyslexia caused by problems with kinesthetic-motor, lateralization and spatial orientation analyzers [15].

The symptoms are as follows [14]:

- kinesthetic-motor analyzer disturbances: improper holding a pencil / pen in the fingers, holding a pencil / pen too close to the tip or end, too much or too little pressure to a surface (a sheet of paper), too much or too little pressure applied to a pencil / pen, predomination of straight lines in the drawings, crossing the lines or contours;

- lateralization and spatial orientation analyzers: changing direction in the drawings (e.g. drawing squiggles from right to left, drawing a vertical line from bottom to top), problems with the appropriate assessment of the size and distance;
- visual analyzer: trouble distinguishing shapes and colors, improper layout of the drawing in relation to the page.

Therapy for dyslexia is very important considering the fact that the number of people who suffer from dyslexia can be estimated even to 17% [10] [11]. This number varies according to research conducted in different countries, e.g. it is close to 9-10% in Poland [1].

It should be also pointed out that dyslexia therapy is often boring for children and, what even worse, its results can be unsatisfactory. Hence, many therapists insist on development new methods which would be more interesting for young patients. Nowadays, just few solutions to solve these problems can be found (e.g. [8] [9] [13] [16]).

2. The Smart Pen

As it was stated in the Introduction, the aim of the project was to create a new kind of a multimodal interface for children with developmental dyslexia. The emphasis was put on dysgraphia problems. The following assumptions were made at the planning stage:

- The interface should make use of a LCD tablet. In this way, it will be possible to measure the pressure put on the surface. It is necessary to obtain the correlation between a hand and an eye. For this reason, ordinary tablets could not be used: a person who uses such a tablet (e.g. drawing a picture) have to see results of his/her work on screen placed far from the tablet.

- The pen, which will be the main part of the interface, should be able to monitor whether the pupil holds it properly, or not.
- The software will include a set of activities supporting a therapy of dyslexia, along with a database of pupils and therapy results.

2.1. Hardware part

Many different models of LCD tablets were tested. Since parameters, such as the number of pressure levels and resolution are not crucial factors in case of the Smart Pen, all tested tablets could be employed in the interface. Furthermore, all tablets have compatible drivers, what is very important and convenient from the software point of view. Unfortunately, almost each kind of a tablet has its own pen type, which will not work in combination with other one. Even tablets from one producer were not compatible with each to other.

The main advantage of the Smart Pen is equipping the tablet pen with three pressure sensors. These sensors are mounted on a special grip which helps to encourage the recommended tripod finger position when holding a pen. The grip is made with plastic material that has properties comparable to hard rubber. Side of the grip is equal to 18 mm, length: 42 mm. The grip is similar to the ordinary pen (or pencil) grips used for dyslexic children who often have poor pen grip.

The pressure sensors can work in the range 10 g – 10 kg. The resistance of the sensor changes (nonlinearly) between 2 MΩ and 3 kΩ - adequately to the pressure. The sensors are available in different sizes of the active part and a shape of a square and a circle. After some preliminary tests, sensors with the circular active part size of 15 mm were chosen. Smaller sensors were not useful, because the area of proper pen handling was simply too small in that case. Bigger sensors demand a too large grip, especially for children fingers.

Signals from the sensors are translated to the PC format using additional converter (also developed in the framework of the project) equipped with processor with built-in A/D converters. As a result, the pen is connected to the PC via USB interface. The converter is very small and has dimensions of 43 x 32 x 22 mm.

The prototype of Smart Pen is presented in the Fig. 1.

Fig. 1. Prototype of the Smart Pen

2.2. Software part

The main aim of the developed application was to allow a pupil to work under teacher or therapist supervision. The application allows continuous monitoring different parameters related to writing. All these parameters are stored in the database and can be easily reviewed, e.g. to observe a therapy progress for each pupil. This is very useful especially from the therapist point of view. Furthermore, the Smart Pen software allows preparing new exercise scenarios and in this way closely matching pupils' problems. Five different activity types are possible to choose: drawing, squiggles, coloring, mazes, joining the dots. All of these activities are similar to suggested by dyslexia therapists [2] [3] [4] [5] [6]. More detailed information about activities is presented in the Tab. 1. Tab. 2 presents the skills developed during the proper performance of each activity. Images of the system shown during exemplary activity are presented in Fig. 2 and 3.

Tab. 1. Activity monitoring implemented in the application

Activity name	**Description**	**Method of controlling the correctness of the performance of activity**	**Monitored parameters**
Drawing	Drawing a picture without any pattern	-	-
Squiggles	Drawing squiggles by joining appearing dots without lifting the hand off surface	Indicators: wrong direction, pen out of an area. Only continuous line is possible	Ratio (in percents) of area used by pupil to area that was available to draw
Coloring	Coloring pictures according to one's ideas, according to pattern or field marking	Indicator: crossing the outline	Number of instances related to crossing the outlines
Mazes	Finding the way through the maze without crossing the maze walls	Indicator: crossing the wall. Only continuous line is possible (from entry to exit of a maze)	Number of instances related to crossing the walls
Joining the dots	Joining dots in an appropriate order	Indicator: improper dot joining. Only continuous line is possible (from the starting dot)	Number of errors

To encourage a pupil to use the software some additional features were added. It is possible to listen to instructions how to complete the activity. The pupil is able to easy change the colors of the drawing lines, the outlines and the background image. After each activity, the pupil is awarded with applause. All pupils' drawings can be printed out (they are stored in the database). Furthermore, the therapist can prepare new drawings for each activity. In this way it is possible to avoid a situation in which the therapy becomes boring for the pupil.

Tab. 2. Skills developed during the proper performance of each activity

	handling pen in proper place	correct pen handling according to the finger placement	correct pen grip	correct pressure on the surface	drawing in correct direction	drawing lines in different shapes	not crossing outlines	consolidating correct order of characters
Drawing	x	x	x	x				
Squiggles	x	x	x	x	x	x	x	
Coloring	x	x	x	x				
Mazes	x	x	x	x	x	x	x	
Joining the dots	x	x	x	x	x			x

Fig. 2. Squiggles activity

For the assessment of whether the exercise was carried out by the child correctly, a set of parameters was established. Monitoring these parameters gives an opportunity to indicate improper performing the activity. Furthermore, parameters from each session are stored in the database and can be easily recalled to assess the therapy progress. In addition to the parameters listed in Tab. 1, following parameters are monitored (it applies to all activities):

• ratio of correct pen holding duration to the time taken to complete the activity [%];

• ratio of too strong grip duration to the time taken to complete the activity [%];

• ratio of too weak grip duration to the time taken to complete the activity [%];

• ratio of duration of correct pressing the pen to the surface to the time taken to complete the activity [%];

• ratio of duration of too strong pressing the pen to the surface to the time taken to complete the activity [%];

• ratio of duration of too weak pressing the pen to the surface to the time taken to complete the activity [%];

• time taken to complete the activity [s];

• has the activity has been completed [yes or no].

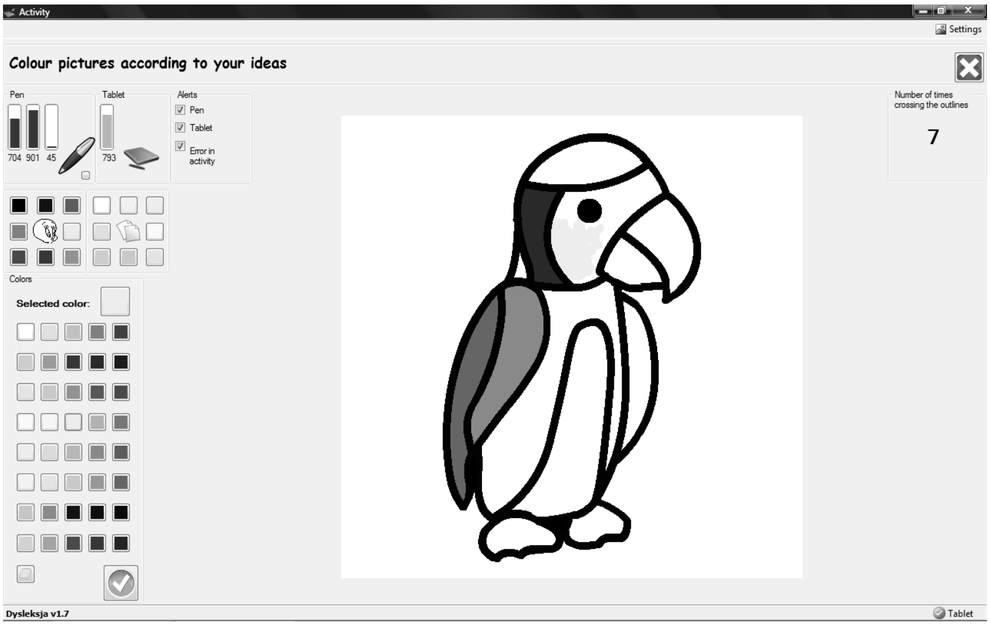

Fig. 3. User interface of developed software (coloring activity)

The pen grip is monitored using two pressure sensors placed under the thumb and index finger. The pressure on the third sensor is usually smaller and it was the reason why this information is omitted. The pressure measured at the correct position of fingers was set as a threshold. Below this value it was considered that the pen grip is too weak or the arrangement of fingers is incorrect. Similarly, the threshold value was determined for the correct pen handling. The indicators are visible in the upper left corner of Fig. 3. All threshold values were established after preliminary tests involving children without dyslexia problems. The application divides users into three groups. The first of them are teachers/therapists, who can prepare sessions for the pupils (it means choosing activities and then particular drawings) and are able to monitor the therapy progress. In addition, teachers can edit the data stored in the database. Login is required for security reason and privacy policy. The second group of users is administrators who can edit the teachers group. The last group is anonymous users who are able to perform activities without saving the obtained results to the database.

2.3. Test series

22 pupils of the age range of 7-10 (primary school, classes I-III) took part in the tests. In the test group were also children with special needs (autism, ADHD, mental retardation). Information about all pupils, relevant to the purpose of the interface, is presented in Tab. 3.

All pupils were asked to carry out 4 activities: coloring, mazes, joining the dots and squiggles. Each session took about 20 minutes. Information about the pen grip and the pressure put on the tablet was not analyzed during the coloring activity. The reason was that this activity took too much time and therefore was classified as the introducing activity.

Special attention was given to the proper pen handling during the all activities. Children were admonished to correct the handling each time the signaling was inducing. Therapist helped younger children to obtain the correct fingers arrangement. In case of older children they were able to correct fingers arrangement while unaided.

Among the whole children group, the reference group was chosen. Only children without any disturbances were selected. Additionally, the teachers did not observed any writing problems in this group. These pupils were marked with grey color in Tab. 3.

Tab. 3. Brief description of pupils

Class	Child	Right- or left-handed	Graphomotorical problems	Problems with correct pen handling	Incorrect grip	Is able to correct fingers arrangement unaided?	Remarks
I	1	r	yes	yes	too strong/ too weak	no	-
	2	r	yes	no	no	no	-
	3	r	yes	no	too strong	no	handles pen very stiffly
	4	r	no	no	no	no	-
	5	r	yes	no	no	no	angular letters shapes
	6	r	no	no	too weak	no	after brain cancer, indicators switched off
II	7	r	no	no	no	no	-
	8	r	no	no	no	no	-
	9	r	no	no	no	no	autism
	10	l	no	no	no	no	cerebral palsy, indicators switched off
	11	l	no	no	no	yes	-
	12	r	no	no	no	yes	risk of dyslexia
	13	r	no	no	no	yes	-
	14	r	no	no	no	no	-
	15	l	no	no	no	no	mild mentally handicapped
	16	r	no	no	no	yes	-
III	17	r	yes	no	no	yes	-
	18	r	yes	no	no	yes	-
	19	r	yes	no	no	yes	suspected dyslexia, ADHD
	20	r	yes	no	no	yes	-
	21	r	no	no	no	yes	-
	22	r	no	no	no	yes	-

It was assumed that that the difficulty level in case of all children should be equal. Therefore, one set of the activities was prepared. Unfortunately, a few children were present during the test session performed by a previous child. In that case, similar drawings were chosen in the mazes and joining the dots activities.

Records of pupils from different class were divided into three groups using vertical lines in all diagrams. Results obtained by children from the first class are presented in the left part of the diagram, then are results of pupils form the second class (the center part) and from the third class (in the right part).

The grey rectangle indicates area that contains results of children from the reference group. The height of the rectangle is a maximum value obtained by children from this group.

The coloring activity

This activity consists in coloring the picture without crossing its contour. Results of this activity are given in Fig. 4.

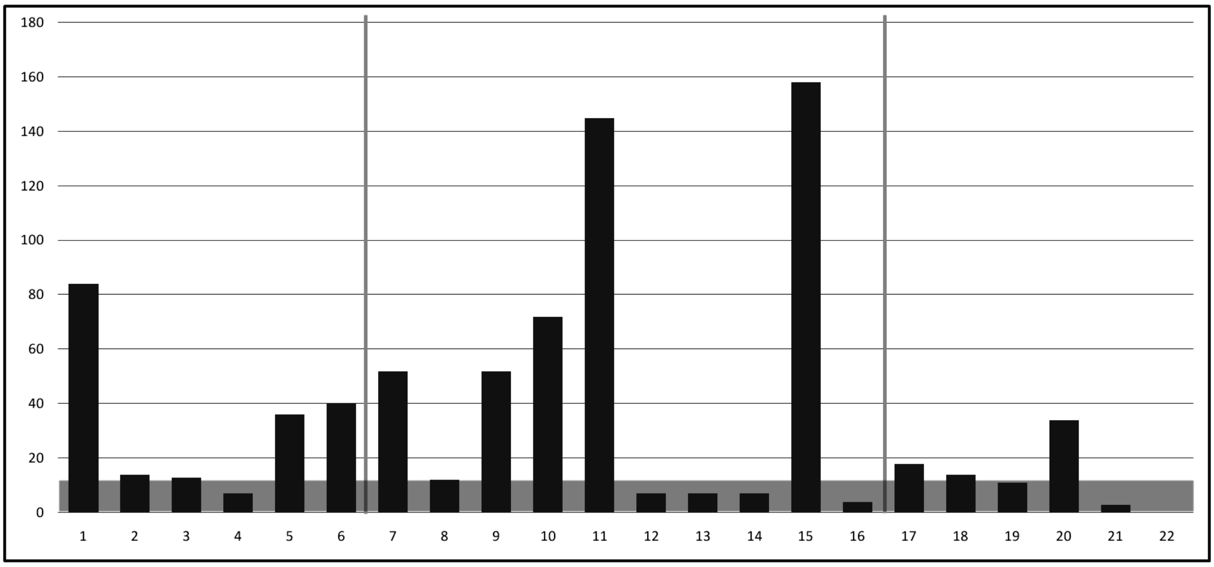

Fig. 4. Number of contour crossing in coloring activity

The weakest results were obtained by pupils No. 11 and 15. The first had no identified disturbances (according to teachers). The latter was mild mentally retarded. Also children with disturbances (No. 6, 9, 10. 15), with graphomotorical difficulties (No. 1, 5, 20) and two without diagnosed disturbances (No. 7, 11) crossed contours much more frequently (even twice as much) than children with the worst result from the reference group. Remaining pupils, even some with diagnosed problems (e.g. pupil No. 12 with dyslexia), had results similar to these obtained by children from the reference group.

Squiggles activity

The activity consists in copying a shape, without lifting the hand from the tablet surface. Dots appearing on the screen show the proper direction of the drawing. Three parameters were measured and stored during this activity:

- ratio (in percents) of area used by pupil to area that was available to draw;
- number of the hand lifts from the surface (Fig. 5);
- time taken to complete the activity.

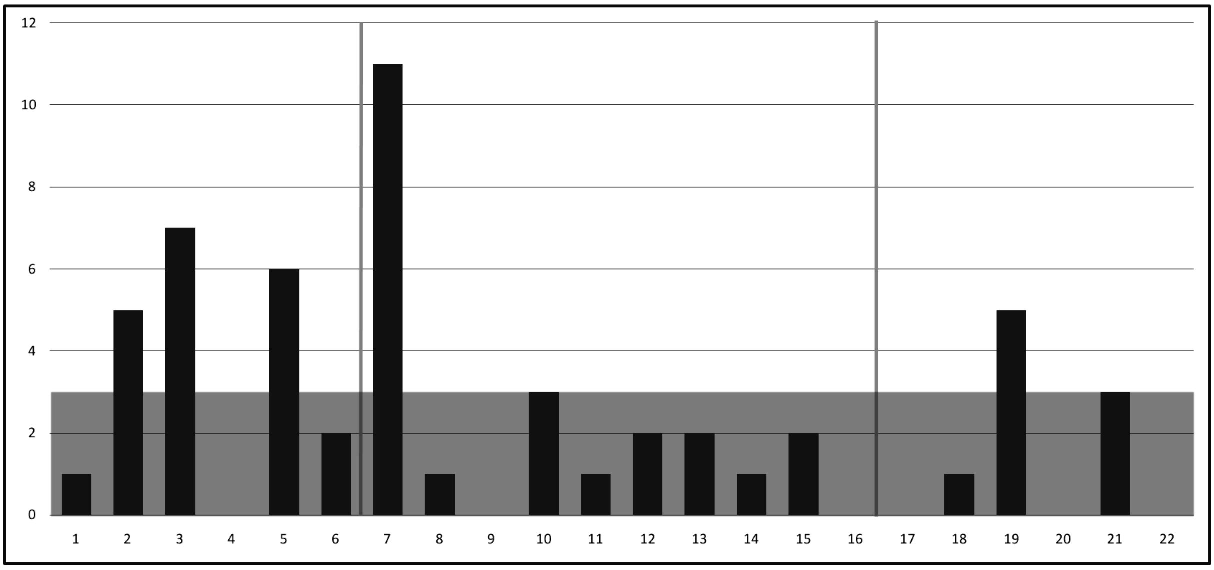

Fig. 5. Number of hand lift ups from the surface (squiggles activity)

The smallest ratio was obtained by some elder pupils (second and third classes) from the reference group. Major problems had children with autism (No. 9), cerebral palsy (No. 10) and two children with graphomotorical disturbances (No. 1 and 20). Results of remaining children were similar to the results of pupils from the reference group.

Surprisingly, the child (No. 7) who lifted the hand most often did not indicated any disturbances. Worse results than pupils from the reference group obtained younger children with confirmed graphomotorical problems (No. 2, 3, 5) and child with suspicion of dyslexia (No. 19).

Completion of the activity took the longest to children with graphomotorical problems (No. 1, 2, 3) and children No. 6 (a child after brain cancer), No 10 (cerebral palsy) as well as child No. 19 (suspicion of dyslexia).

Mazes activity

Children were asked to find the way through a maze. The following parameters were monitored:

- number of times crossing the outlines (Fig. 6);
- time taken to complete the activity.

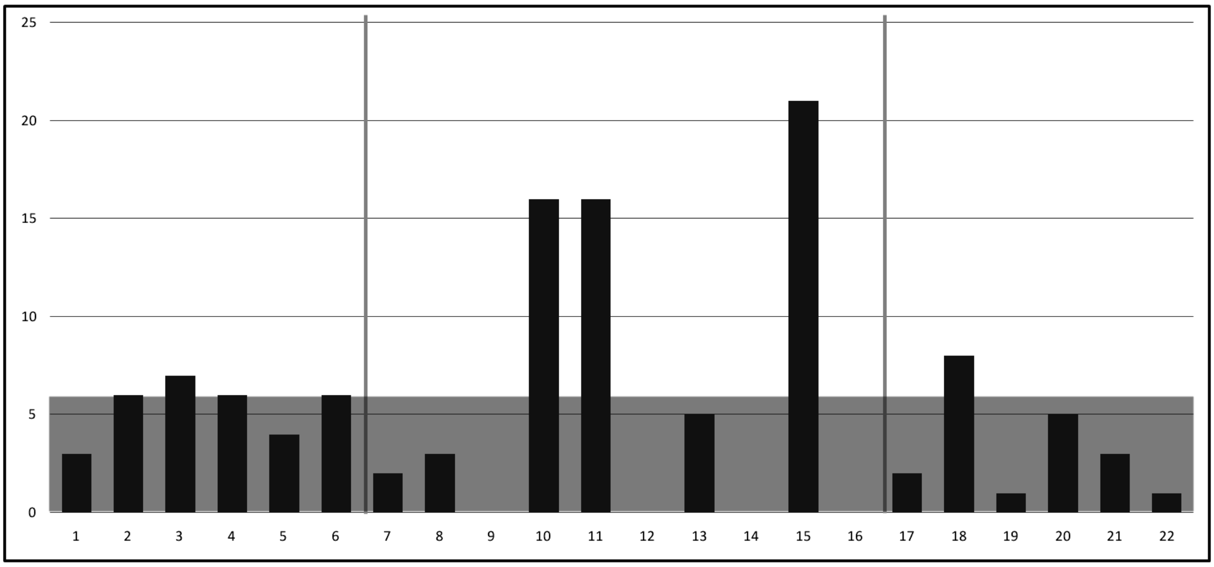

Fig. 6. Number of instances related to crossing outlines in mazes activity

In this activity, pupils from the second class crossed border most often, i.e. marked with No. 10 (a child with cerebral palsy), No. 11 (a child with no disorder) and No. 15 (mild mentally retarded). Other children had similar results to the results of children from the reference group.

Similarly to the results obtained in the squiggles activity, the activity took the longest to children with graphomotorical problems from the first class (No. 1, 2) and the child with cerebral palsy (No 10). Other students obtained results similar to those obtained by children from the reference group.

Joining the dots activity

The activity consists in connecting dots accordingly to the increasing numbers. The monitored parameters were:

- time taken to complete activity (Fig. 7);
- ratio (in percents) of time during which pupil did not write to time taken to complete activity (Fig. 8).

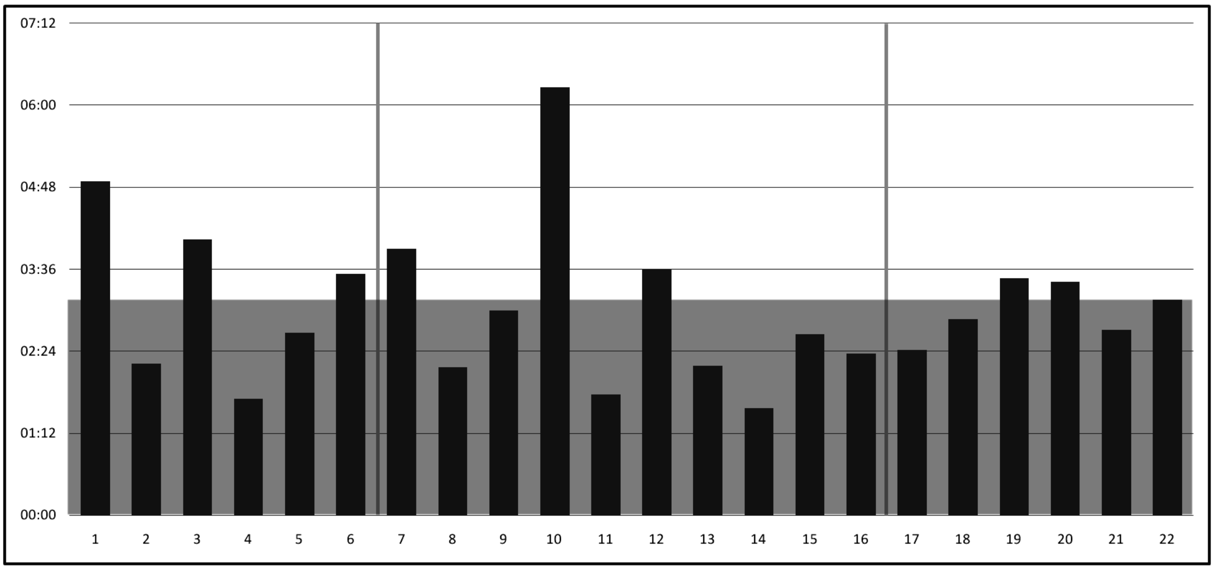

Fig. 7. Time taken to complete activity (joining the dots activity)

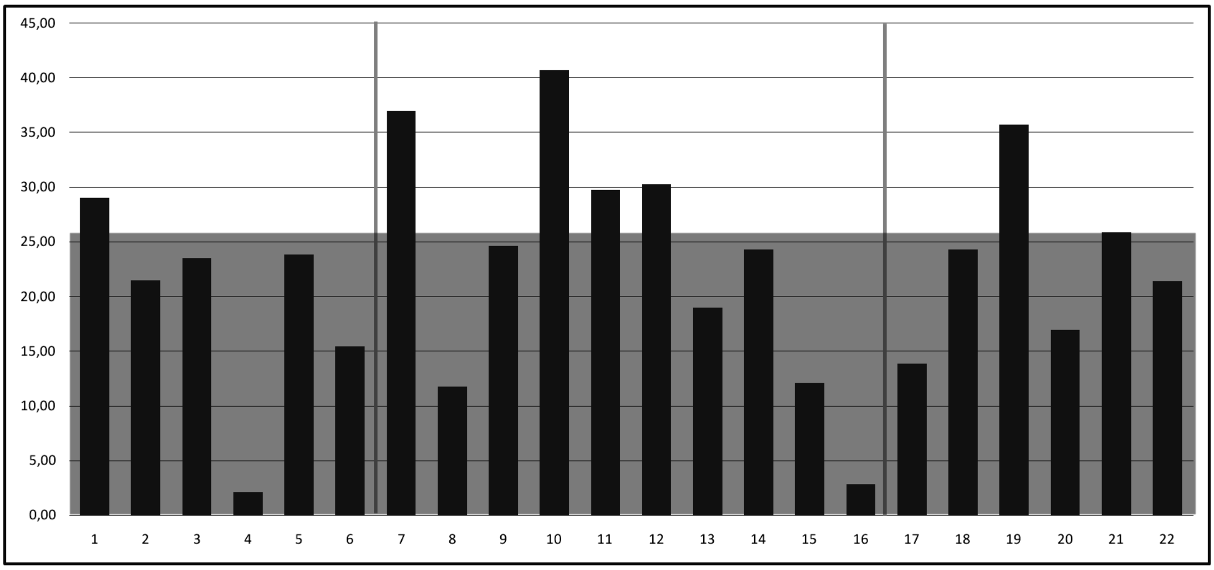

Fig. 8. Ratio (in percents) of time during which pupil did not write to time taken to complete activity (joining the dots activity)

Completion of the activity took the longest to children with graphomotorical problems (No. 1 and 3) and the child with cerebral palsy (No. 10).

The ratio of the time during which pupil did not write to the time taken to complete activity may be interpreted as the ratio of the time needed to arrange dots in correct order to the time-duration of drawing lines between these dots. From this point of view, pupils with graphomotorical disturbances (No. 1, 3, 20), which need more time to complete activity then pupils from the reference group, obtained similar values of the ratio as pupils without any problems. The opposite situation is for pupils No. 7, 12, and 19. It can be explained by the fact that children with dyslexia and children No. 7 and 12 spent more time finding the correct dots order, while pupils with graphomotorical have some problems with drawing.

Summarizing the results obtained by children in various activities, it can be concluded that the weakest results were obtained by the child with cerebral palsy (No. 10) from the second class. Clear problems with fit in the limits had also mild mentally retarded child (No. 15). These observations are quite obvious. More interesting, children No. 7 and 11 also have poor results. In that case, teachers did not observe any problems. On the other hand, the pupil

No. 12 obtained results comparable to those obtained by children from the group of reference, except of the joining the dots activity.

Among pupils with graphomotorical problems from the first class, the most serious problems with completion of activities had the pupil No. 1. He performed all activities very slowly, with the results differing from those obtained by children without any disorders. Other children (with graphomotorical problems) obtained different results depending on the type of activity.

Among children from the third class, the worst results obtained pupils No. 20 (with confirmed graphomotorical problems) and No. 10 (confirmed dyslexia). The remaining children obtained results similar to students from the reference group. On this basis, it appears that the activities were quite simple to complete for that age group.

The pen grip values analysis

In the case of two pupils (No. 6 and 10) it was necessary to switch off indicators of improper pen handling. These children had a problem holding the pen correctly even for a short time.

As the results for all activities were similar, only graph for the squiggles activity is presented (Fig. 9). The graph presents the percentage of time in which the pen grip values were assigned to successive intervals. Bars correspond to small values of the pen grip represent too weak pen grip or improper pen holding. In contrast, bars related to bigger values of the pen grip mean that the pen was held properly.

Based on the above figures, it is visible that children No. 6 and 10 had the weakest pen grip in case of all three activities. This is in line with expectations: the first one was a child after brain cancer, the second - with cerebral palsy. Very low values of the pen grip were also observed for the pupil No. 1, especially during mazes activity. The teacher proved this observation.

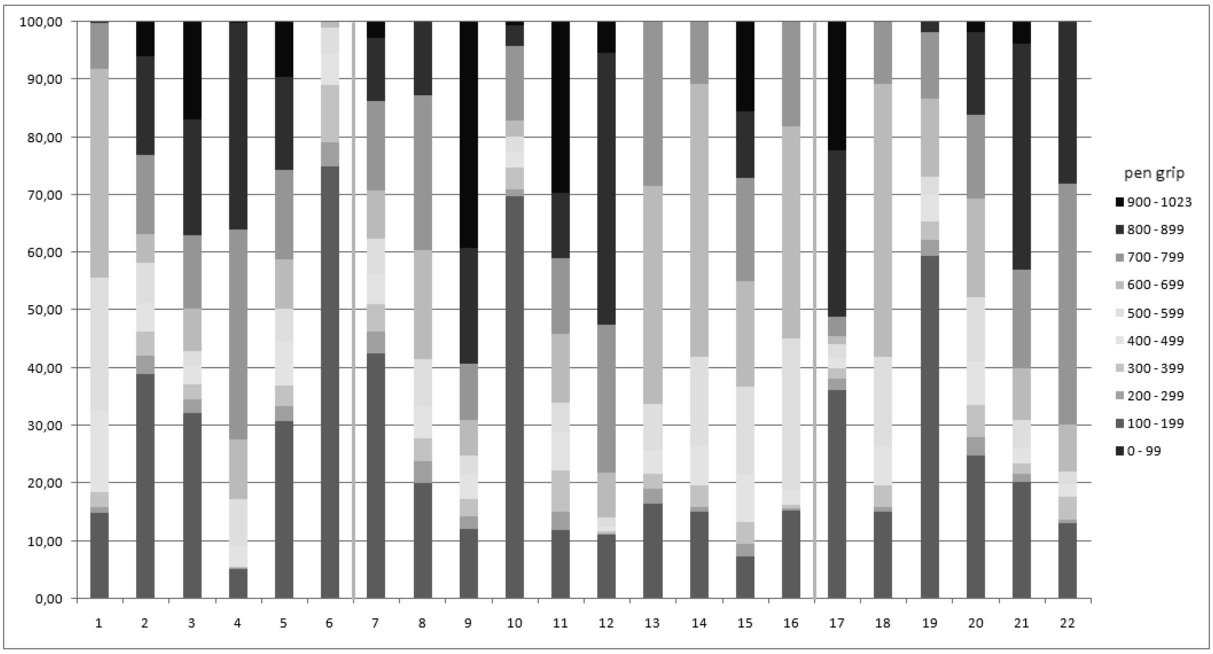

Fig. 9. Pen grip values – squiggling activities

The strongest pen grip was observed in case of children No. 3 (stiff pen handling according to the teacher) and No. 15 (mild handicapped mentally). A very strong pen grip, especially during the squiggles activity, had also the child with autism (No. 9), the child without any confirmed disturbances (No. 11) and a child with graphomotorical problems (No. 17). Pupils from the reference group obtained results below the value of 900. This value was set as the upper threshold. The pen grip represented numerically above this value is indicated by the application as improper.

Results obtained during the squiggles activity were chosen for the analysis of the proper fingers placement. In this activity children tried to not change the fingers arrangement since it could result in lifting the hand off the surface. From that reason, the pen grip values observed in that activity are significantly higher than in other activities. In Fig. 10 is visible that the correct fingers arrangement was the most difficult for pupils No. 6 and 10. Children from the reference group held the pen correctly by more than 85% of the time taken to complete activity. These results proved that the pressure sensors were located correctly.

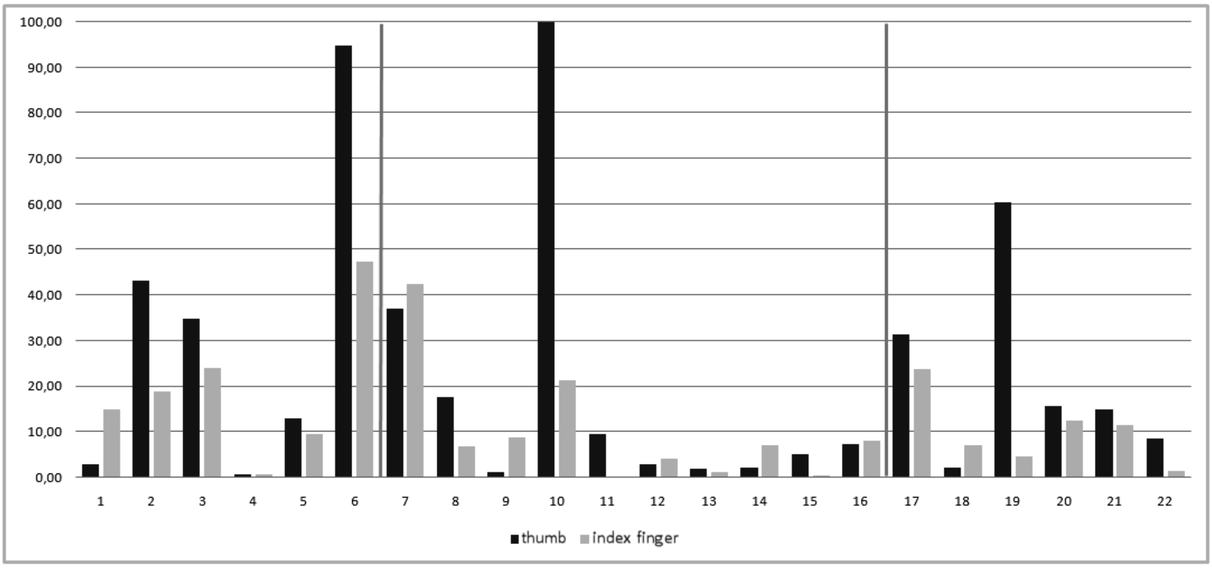

Fig. 10. Ratio of too small pen grip duration to the time taken to complete squiggling activity

The pressure on the tablet values analysis

The results of pressure on the tablet monitoring are presented in Fig. 11 (as in the pen grip analysis, the squiggles activity was chosen). Similarly to the previous results, the highest values of the pressure on the tablet were observed for the child No. 11 (theoretically not affected by any disturbances) and No. 3 (having confirmed problems with holding the pen).

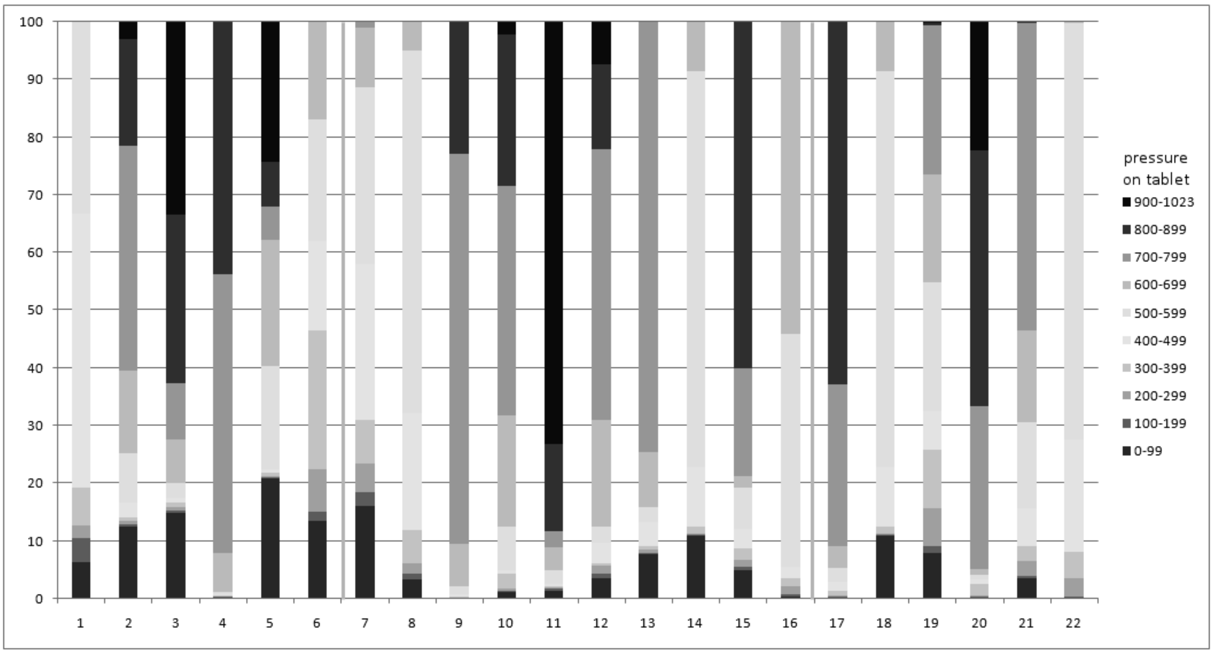

Fig. 111. The pressure on the tablet values – squiggling activity

Interesting results was obtained for the child No. 6 (after brain cancer treatment). In the mazes activity he pressed on the tablet very weakly (the worst result in the whole group), but in the – joining the dots activity obtained results equal to the children from the reference group. Poor results were also observed for the child No. 7, who admitted that pressed the pen lighter than usually.

Similarly to the pen grip values, none of the pupils exceeded value of 900. Since that, that value was set as upper threshold. All children pressed on the tablet the most during the squiggles activity. The explanation of above is the same as in the case of the pen grip – children tried not to lift the hand off.

Statistical analysis

To verify whether parameters measured by the Smart Pen can be used as indicators of graphomotorical problems, additional analyses were made. For this purpose, the correlation coefficient between information from teachers and therapist and results obtained by children was determined.

In order to calculate the correlation coefficient, opinions of teachers and results were presented in binary form - child met the criterion or not. The level of confidence was set to 5%, in result (test group of 22 people) the critical value of correlation factor was equal to 0.3598.

Tab. 4 presents the calculated coefficients of correlation between the results obtained in the exercises and a description of children by teachers. It can be noticed that the strongest correlation occurs in case of squiggles activity results. The problem was spotted in case of the child No. 11. All results indicate that this child has graphomotorical problems, but it is unclear why teachers did not notice it. It is also possible that during activities the child was not focused enough and it resulted in so poor results. For all following analyses the child No. 11 will be added to the group with problems. The results are presented in the Tab. 5.

Tab. 4. Correlation coefficients between the results obtained in the exercises and description of children by teachers

	Coloring activity - Number of instances related to crossing the outlines	Squiggles activity - ratio of area used by pupil to area that was available to draw	Mazes activity - number of instances related to crossing the outlines
Graphomotorical problems and/or disease	0.1742	0.4866	0.1692
Graphomotorical problems and/or disease and child No. 11	0.4110	0.5551	0.3510

Table **Błąd! W dokumencie nie ma tekstu o podanym stylu.**. Correlation coefficients for different parameters

	Squiggles	Mazes	Joining the dots
Too weak pen grip	0.4109	0.5657	0.5181
Too weak pressure put on the tablet	0.6446	0.4384	0.4536
Too strong pen grip	0.0871	0.0987	0.1361
Too strong pressure put on the tablet	0.4324	0.3363	0.5804

The correlation coefficient between the pen grip below the threshold value and the children diagnose exceeded the critical value for all activities. The same situation is for the pressure put on the tablet. It can be stated that the system properly detects such cases.

In contrast, results in case of too strong pen grip and too strong pressure put on the table are not distinct. It may be explained by the fact that children could have been under stress. They tried to hold the pen in the most correct way possible. In result, they held the pen too strong. This observation was proven even by the children: after completion of activities they admitted that held the pen more than during normal writing.

2.4. Current work

Exercises described above are intended primarily for the dysgraphia therapy. However, it is possible to expand the developed system with new exercises modules. This possibility has been used to add exercises for people with dyscalculia. The task is to solve a simple mathematical equation and then coloring the part of the figure relevant to the equation outcome (Fig. 12). During the exercises different parameters are measured (the pen grip, the pressure on the tablet, number of times crossing the outlines), information about whether the activity was done correctly is also saved in the database.

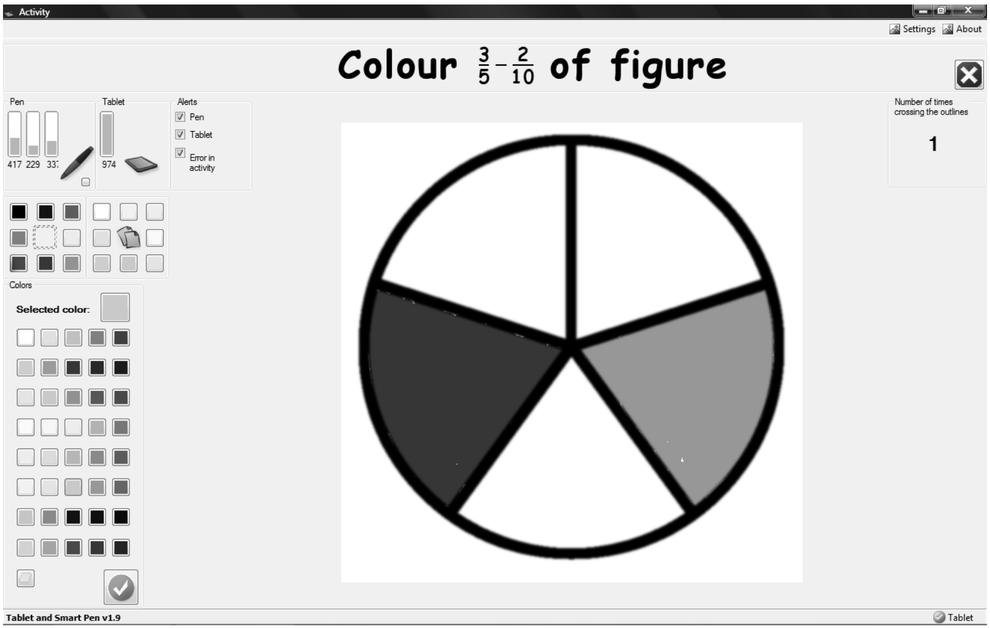

Fig. 122. Maths riddles – activity for children with dyscalculia

3. Conclusions

Tests showed that teachers and therapists are very keen on using the new tool for dysgraphia therapy. Children taking part in tests also expressed their interest in working with such a system. Furthermore, using the Smart Pen it is possible to distinguish children without motoric disruptions and those who may be affected by dyslexia/dysgraphia. It can be done by analyzing different parameters, such as the pen grip and the pressure put on the tablet. Children with graphomotorical problems more frequently obtained worse parameters in activities that required precise pen movements. But in some cases differences in comparison to children without problems were not significant. There are two explanations of that phenomenon: children were focused on doing activities or simply it was a result of systematical therapy.

The Smart Pen interface can be considered as a prototype of a new kind of a system that may be used to assist the therapy of children with graphomotorical disturbances. The special pen and the tablet, together with the software, may be treated as a kind of a new platform for organizing different types of writing and drawing activities. New features can be easily added and in this way the possibilities of the Smart Pen will be broaden. E.g. it is possible to implement some additional activities related to learning of mathematics. It should be also pointed out that although there are many kinds of software employing computer to the therapy, there is no such an advanced system on the market, yet.

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