

# Digital Tools in Speech Therapy: Features of Supporting Children with Speech Needs in an Inclusive Environment

Eliana Danilavichiutie<sup>1</sup>

<sup>1</sup>Department of Speech Therapy, Mykola Yarmachenko Institute of Special Education and Psychology, National Academy of Educational Sciences of Ukraine, Kyiv, Ukraine, <https://orcid.org/0000-0003-3911-7612>

E-mail: elyana\_d@ukr.net

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## ABSTRACT:

The growing number of children with speech disorders in inclusive institutions in Ukraine necessitates the search for new solutions for systematizing speech therapy care that would combine high efficiency with accessibility and individualization of the correction process. The purpose of the study is to empirically verify the effectiveness of digital tools organized according to the neuro-psycho-linguistic-synergistic model in correcting speech disorders in preschool children in an inclusive environment compared to traditional Ukrainian methods. The controlled study was based on 45 children aged 5–7 years with phonetic-phonemic underdevelopment, dysarthria and delayed speech development in two inclusive preschool institutions in Kyiv (control conditions, n=22, traditional methods; experimental conditions, n=23, traditional methods and 10 computer programs at four levels). The experimental group demonstrated a twofold increase in the rate of progress in all parameters: the production of speech sounds deteriorated by 58% compared to 33% in the control group ( $p<0.001$ ,  $d=1.89$ ), phonemic hearing deteriorated by 78% compared to 37% ( $p<0.001$ ,  $d=2.24$ ), vocabulary deteriorated by 50% compared to 24% ( $p<0.001$ ,  $d=1.26$ ). The results confirm the synergy of using digital tools with the traditional approach and prove the effectiveness of the neuropsycholinguistic-synergistic strategy for structuring speech therapy support in the inclusive environment of Ukraine.

**Keywords:** speech correction, speech therapy support, neuroplasticity, gamification, alternative communication

## 1. Introduction

The growing number of children with special educational needs in inclusive institutions in Ukraine is a challenge for speech therapy services, as corrective support must be provided effectively in conditions of limited resources and

increasing workload on specialists. The Ministry of Education and Science of Ukraine notes that as of 2024, more than 80,000 children with speech disorders are students of inclusive groups in preschool and school institutions, which means the need to find innovative methods of

organizing speech therapy that would combine high efficiency with accessibility and individualization of the correction process. At the same time, the digitalization of the educational process opens up new opportunities for integrating technologies into traditional speech therapy methods, but this should occur in conditions of scientifically based approaches in accordance with the characteristics of children's speech development and the characteristics of work in an inclusive environment.

Our theoretical basis is the concept of neuropsycholinguistic-synergistic organization of speech therapy care for population groups with special speech needs, developed by Danilavichutė (2024) and combining four levels of corrective influence: neurological (functioning of articulatory zones and neuroplasticity), psychological (motivation, attention, emotional state), linguistic (phonetics, vocabulary, grammar) and synergistic (interaction of all systems in an individual approach to treatment). This concept develops the ideas proposed by Danilavichutė (2021) regarding the new definition of educational challenges in the field of functional speech, and provides a methodological basis for the correction of speech disorders that goes beyond traditional symptom-based intervention. However, the issue of effective implementation of this concept through the assimilation of digital tools is insufficiently researched, especially in relation to inclusive education in Ukraine.

I believe, that nowadays there is a growing trend of using digital technology in the practice of speech therapy, as shown by foreign research. Tucker (2021) demonstrated that digital technologies can effectively supplement traditional children's speech therapy; increasing child encouragement and practice opportunities. Nevertheless, most studies are concentrated on one application or technology only and do not develop a comprehensive model that represent the integration of applications to a complex system of speech therapy intervention. For description of the experience of using digital technologies during speech therapy in the Ukrainian context, see Kolomoiets (2023), and for study that researches the prospects of online

resources and mobile applications in corrective work with children combined pathology is Mykhailenko (2022)—a control group was not included for either study, so it was not possible to assess the effectiveness of digital or traditional methods. Chernychenko (2024) noted that building competence digitally and ability to generate information for speech therapists is a necessity in today's digital civilization, still there are factors of introducing digital tool into traditional correctional methods left unaddressed.

Simultaneously, smart use of digital technology is necessary in working with preschool children. According to Madigan et al. (2019), high screen time was significantly negatively associated with the findings of child development screening, endorsing that digital technology should be implemented in collaboration with a speech therapist and not as a substitute for face-to-face means of communication. This is why there is a requirement for integrative models, where digital media are incorporated into traditional corrective processes and added to them rather than replacing those; but as an integral part of the treatment, social interaction, emotional contact with the speech therapist continue to play a significant role in the treatment.

A comparison of the scientific literature shows that there are many gaps in research on the use of digital tools for speech therapy correction. First, most international research is also conducted in an English-speaking environment, and the uniqueness of the Ukrainian language (complex phonetic system, variety of grammatical forms, peculiarity of phonemic structure) implies the need to adapt digital tools and experiment with their effectiveness on the Ukrainian child population.

Second, existing research mainly focuses on individual variables of digital technologies (such as motivation, sound quality, etc.), without investigating all levels of the language system and their simultaneous impact by digital tools. Third, there are no controlled studies comparing traditional Ukrainian speech correction methods (Tarasun, Ribtsun, Trofimenko, Sobolovich) and

an integrated approach that combines these methods with digital tools structured on a clear theoretical basis. Fourth, the impact of digital technologies on the social inclusion of children with speech disorders, in particular non-verbal children who need alternative communication strategies, has not been sufficiently studied.

## 2. Literature Review

The theoretical and methodological basis of the study is based on three main areas of scientific knowledge: neuropsycholinguistic-synergistic approach to the correction of speech disorders, traditional Ukrainian methods of speech therapy, and modern digital technologies in speech therapy. Coordination of these areas will make it possible to develop a more detailed system of speech therapy care, which will combine both traditional correction methods and new technological approaches.

### ***Neuro-psycho-linguistic-synergistic approach to the correction of speech disorders***

The conceptual basis of the study is the neuropsycholinguistic-synergistic model of speech therapy for individuals with special language needs Danilavichiutė (2024). This model is based on four interconnected levels of corrective influence, including: the neurological level, which concerns the work of the articulatory zones of the cerebral cortex and the processes of neuroplasticity; the psychological level, which supports the motivational, emotional and cognitive elements of the corrective process; the linguistic level, which includes all elements of the language structure (phonetics, phonology, vocabulary, grammar, pragmatics); and the synergistic level, which links all levels into a personalized intervention model, taking into account the unique features. The assumption of this approach is that the effectiveness of corrective intervention does not depend on the sum of the effects at individual levels, but rather on their interaction, in which change at one level supports and accelerates changes at other levels.

Dehtiarenko and Pavlova (2019) developed neuropsychological foundations for the diagnosis and treatment of speech disorders, characterizing a complex system of assessment of cognitive processes that accompany the development of speech: auditory and visual attention, types of memory and voluntary regulation of activity. The authors indicate that the neuropsychological functions that underlie speech skills are of great importance for the success of speech therapy correction. Lopatynska (2020) supplemented this knowledge by explaining the possibilities of using neurostimulation technologies in the process of correctional work with children with speech disorders, in particular the possibility of creating conscious control over articulatory movements using biofeedback. The systematization of the theoretical foundations of speech activity and its disorders was carried out by Sukhoviiienko (2025), who substantiated the psycholinguistic model of speech acts, which includes the stages of planning, programming, implementation and control of speech utterances. These stages are important for understanding what corrective intervention should be aimed at at different levels of the speech system.

### ***Traditional Ukrainian methods of speech therapy correction***

The school of speech therapy in Ukraine has a remarkable history of creating effective mechanisms that are used to treat various types of speech disorders in children. Korobeinykova (2025) created a psycholinguistic model of studying and correcting speech in preschoolers, which is based on the concept of Sobolovich and involves establishing speech defects through the prism of psycholinguistic mechanisms of speech production and comprehension. This methodology emphasizes the need to deal not only with the external manifestations of disorders (symptoms), but also with the processes that lead to them, such as the establishment of speech operations of selection, combination and transformation of speech units.

Ribtsun (2011) explained in detail the phonetic-phonemic aspect of children's phonemic readiness for literacy and developed a program-

methodical complex for the correction of phonetic-phonemic underdevelopment, which consists of a system of articulation exercises, reproduction of sounds in various forms (imitative, mechanical, mixed), a series of stages of development of automation of sounds (isolated, in syllables, words, sentences, coherent speech) and the development of phonemic processes. This complex is based on correctional work in speech therapy institutions in Ukraine, which, when systematically applied, turns out to be highly effective.

Tarasun (2017) developed a detailed system of speech therapy that provides theoretical and methodological foundations for working with children with speech needs in an inclusive environment. This system includes general didactic principles in addition to specific principles of corrective pedagogy, which makes the combination of educational and corrective activities within the framework of one educational process. The author emphasizes the importance of creating a specially structured speech environment that can stimulate children's communicative activity and provide them with natural conditions for practicing speech skills.

The methodology for diagnosing and correcting general speech underdevelopment in preschool children is a methodology that includes all elements of the speech system, and the correction work is carried out in stages, starting with the creation of sensorimotor conditions that allow speech to occur, and ending with the formation of more complex forms of speech activity Trofymenko (2014). The diagnostic tools created by the author allow to objectively assess the state of each of the components of the speech system and determine priority areas in which corrective intervention can be planned, therefore they are also necessary for drawing up individual correction courses.

### ***Digital tools and innovative technologies in speech therapy***

The current state of development of speech therapy This corresponds to an active studying of potential introduction of digital technologies in the correction process. Kurienkova (2023a) also

outlined innovative technologies of preschool speech in-service training, multimedia presentations, interactive boards, computer programs for logofatric therapy and noted that the effectiveness of technologies is provided by means of their methodologically reasonable integration in the traditional system of curative care. The system developed by Olkhovska (2021) is based on the application of IT for development of coherent speech in senior preschool children with the help of advanced technology support means during training to narrative-speaking activity, i.e. mnemonic methods combined with visual illustrations; sensory-graphic schemes and mental maps allowing to organize external subject-specific assistance during preparation for internal speech.

Telepractice systems for speech therapy have been found to be effective as evidenced by research from overseas. Attwell et al. (2022) showed that synchronous teletherapy (using video communication in real time) is not inferior to face-to-face therapy for a wide range of language disorders, and asynchronous solutions (standalone applications use) are an adjunct but not an alternative of mainstream therapy. Saeedi et al. (2022) investigated the use of digital games in therapy with children and confirmed that game applications including an incentive system increased children's motivation to perform exercises as well as the active implementation of homework which translated into faster progress, particularly at the stages of sound automation and vocabulary enhancement.

There are some literature reviews, which prove that the theoretical background of working with digital tools in traditional speech therapy is quite solid, but we do not come across any baseline studies, which would measure experimental procedures in Ukrainian reality and demonstrate the effectiveness of the approach for generalizing the results at each level of the language system.

### **3. Materials and Methods**

The study is based on the neuropsycholinguistic-synergistic method of structuring speech therapy

assistance for children with speech disorders in a general education school (Danilavichiutė, 2024). Based on this method, four scales of corrective influence were included: neurological (functioning of articulatory zones, neuroplasticity), psychological (motivation, attention, emotional state), linguistic (phonetics, vocabulary, grammar) and synergistic (interaction of all systems in an individual intervention model). The study had a comparative design and two groups of participants; one of the groups was considered the control, as it received traditional correction methods based on Ukrainian techniques, and the other group was considered experimental, as it received traditional methods, which were additionally supplemented with digital tools organized according to the four levels of the neuropsycholinguistic-synergistic model.

The study sample consisted of 45 children aged 5–7 years with speech disorders who studied in two inclusive preschool educational institutions in Kyiv. Inclusion criteria were age from five to

seven years, confirmed diagnosis of phonetic-phonemic underdevelopment, dysarthria or delayed speech development, enrollment in an inclusive preschool group, normal hearing (as assessed by audiometry), absence of severe intellectual disabilities and written parental consent to participate in the study. Exclusion criteria included, among others, severe autism, severe intellectual disability, hearing loss over 40 decibels and other severe neurological conditions that could seriously affect the results of the corrective intervention. The quasi-randomization technique was used to form the groups: the control group consisted of children from the first preschool institution, and the experimental group consisted of children from the second. The first diagnostics, conducted in September 2024 using the methodology of Trofymenko (2014) and Dehtiarenko and Pavlova (2019), confirmed the statistical homogeneity of the groups in all important parameters. The description of the participants is detailed in Table 1.

**Table 1.** Characteristics of study participants

| Parameter                                            | Control group<br>(n=22) | Experimental group<br>(n=23) | Statistics                   |
|------------------------------------------------------|-------------------------|------------------------------|------------------------------|
| Age (years), M±SD                                    | 6.1±0.8                 | 6.0±0.7                      | t=0.43, p=0.67               |
| Gender (boys/girls)                                  | 12/10                   | 10/13                        | χ <sup>2</sup> =0.06, p=0.81 |
| Phonetic-Phonemic Disorder                           | 9 (40.9%)               | 10 (43.5%)                   | –                            |
| Dysarthria                                           | 7 (31.8%)               | 7 (30.4%)                    | –                            |
| Delayed Speech Development                           | 6 (27.3%)               | 6 (26.1%)                    | –                            |
| Nonverbal children                                   | 0                       | 3 (13.0%)                    | –                            |
| Phonetic pronunciation<br>(number of correct sounds) | 12.3±2.1                | 12.5±2.0                     | t=0.32, p=0.75               |
| Phonemic hearing (% correct<br>answers)              | 45.2±8.3                | 44.1±7.9                     | t=0.45, p=0.65               |

Source: compiled by the author based on Dehtiarenko and Pavlova (2019), Trofymenko (2014)

As shown in Table 1, the two groups were similar in terms of age, gender, diagnosis distribution, and baseline speech characteristics (p>0.05 for all parameters), ensuring the accuracy of subsequent

comparative analysis of the effectiveness of the intervention. The only difference was that three nonverbal children were included in the experimental group, which was supposed to use

Augmentative and Alternative Communication (further – AAC) communicators.

In the control group, correctional work was carried out only using traditional Ukrainian methods on a systematic and comprehensive basis. The logodidactics system of Tarasun (2017) guaranteed the gradual acquisition of speech skills through specially structured learning situations in the form of didactic games “Magic Bag” (development of tactile sense and enrichment of vocabulary), “Find a Pair” (distinguishing phonemes and identifying grammatical categories) and the game “Name It Kindly” (forming diminutive-affectionate forms of nouns). The program and methodological complex of Ribtsun (2012) contained articulation exercises divided into the following categories: exercises “Smile”, “Tube”, “Shovel”, “Needle”, “Clock”, “Swing”, “Painter” and “Mushroom”, which were performed in front of each child’s personal mirror in order to find a kinesthetic feeling of the corresponding symmetry of the articulatory organs.

Mechanical formation of sounds was carried out using speech therapy probes (probe-spatula for forming hissing sounds, probe-spatula for forming hissing sounds, probe-sled for forming the sound [P]) and their combinations based on stored sounds.

Automation of sounds was carried out in stages, in isolated positions, in direct syllables (SA, SO, SU), inverted syllables (AS, OS, US), syllables with a consonant cluster (STA, SKO), in words of different component structures (monosyllabic, disyllabic, trisyllabic), in phrases, simple sentences and coherent speech. General underdevelopment of speech was corrected comprehensively using the Trofymenko methodology (2014), which also included the development of phonemic hearing using exercises such as “Clap when you hear the sound [C]”, “Raise the blue flag if you hear a hard consonant, green - a soft one” and the formation of vocabulary using thematic cycles “Vegetables-Fruits”, “Clothing”, “Transport”, “Animals” using thematic and plot pictures, the formation of grammatical categories using exercises related to

the agreement of adjectives. Connected speech was developed through tasks on telling short stories with the help of supporting pictures, writing stories using a sequence of plot pictures and describing objects according to the scheme (name, color, shape, size, parts, purpose). Individual lessons were held twice a week for 30 minutes, as well as lessons in small groups of 4–5 children, during which children participated in joint speech tasks, which also contributed to the development of communication skills and social interaction in an inclusive environment. (Appendix B, Table B.1)

Instead, the experimental group was subjected to the same traditional correction methods (according to the methods of Tarasun, Ribtsun, Trofymenko), but with the addition of digital tools planned in the neuropsycholinguistic-synergistic model of Danilavichiutė (2024). At the neurological level, the Articulation Station application gave children the opportunity to see a three-dimensional animated image of the articulatory apparatus while performing the “Smile” and “Tubochka” exercises, which allowed them to better perceive the location of the tongue, lips, teeth and palate in space. The Speech Blubs application was based on real-time facial recognition technology and sound wave analysis: the child saw an animated character on the tablet screen, which showed him how to articulate the sound correctly, and the system analyzed the efforts made by the child to articulate the sound and provided instant visual feedback (green screen for successful articulation of the sound, red screen for unsuccessful articulation of the sound, sound wave graph). Breathing exercises such as “Blow out the candle”, “Blow out the snowflake”, and “Roll the ball” were performed using applications in which the tablet’s microphone responded to the force and duration of exhalation, and the movement of objects on the screen made the breathing exercises more attractive to children.

From a psychological perspective, game elements were applied, including the use of a sound shooter, where the child could shoot down any flying objects containing the correct pronunciation of the sound and receive points for

it, “Pop bubbles with the sound [P]”, where each bubble contained a syllable or word with an automated sound, and the child had to pronounce it correctly for the bubble to burst. The system provided incentives in the form of a growing graph and virtual awards (medals, stars, cups) that showed progress, and incentives were provided for correct pronunciation, as well as unlocking new levels, which greatly motivated children to perform the exercises daily and gave a sense of achievement (Kabelnikova & Savinova, 2024). At the linguistic level, interactive games for

training phonemic hearing were presented: the game “Phoneme Detective” (the child had to hear a given sound among others that appeared on the screen quite quickly), digital flash cards where words were voiced by native Ukrainian speakers, and the Endless Alphabet application with animated letters that started moving and appeared on the screen to demonstrate the corresponding sounds for studying graphic images of phonemes. Table 2 provides a detailed systematization of digital tools by level of intervention.

**Table 2.** Digital tools of the experimental group by intervention levels

| Level   | Tool                    | Function                                        | Frequency of use                |
|---------|-------------------------|-------------------------------------------------|---------------------------------|
| NEURO   | Articulation Station    | 3D visualization of articulation                | 2 times/week in class           |
| NEURO   | Speech Blubs            | Real-time sound recognition                     | 2 times/week in class           |
| NEURO   | Breathing Apps          | Control of the force and duration of exhalation | Daily at home                   |
| PSYCHO  | “Sonic shooter”         | Gamification, points system                     | 10–15 minutes at home every day |
| PSYCHO  | Progress Dashboard      | Visualization of progress dynamics              | Permanent access                |
| LINGVO  | “Phoneme Detective”     | Development of phonemic hearing                 | 3 times/week                    |
| LINGVO  | Digital Flashcards      | Enriching the vocabulary                        | Daily at home                   |
| LINGVO  | Endless Alphabet        | Learning graphemes                              | 3 times/week                    |
| AAC     | Grid 3 / Proloquo2Go    | Alternative communication                       | Constantly (3 children)         |
| Parents | Parental Monitoring App | Homework and reports                            | Daily                           |

Source: Systematized by the author based on Attwell et al. (2022), Saeedi et al. (2022), Kabelnikova and Savinova (2024)

Table 2 demonstrates that digital tools were applicable on all four levels corrective influence and were used under time individual classes with speech therapist and home on daily basis. In case three nonverbal children with experimental samples were proposed AAC communicators Grid 3 and Proloquo2Go with sets icons selected individually depending from communication needs child: child could to touch pictograms on

tablet (for example, an image toys, food or actions), system synthesized speech in Ukrainian in the language, and baby could express your desire, answer speech therapist under time group sessions or answer on question for parents children who belonged to experimental groups, there was provided special mobile Parent Monitoring App, where speech therapist appointed weekly home task in in the form of

short video lessons (duration from 5 to 10 minutes) and interactive games. Parents recorded the completion of exercises and the time spent by the child on the exercises, and the system generated weekly reports on the duration of the exercises, the frequency and quality of the homework, which were automatically sent to the speech therapist. (Appendix B, Table B.2) This played a significant role in involving parents in the correction process and ensuring continuity of speech therapy support.

Diagnostic tools were a detailed assessment of all elements of the speech apparatus and other psychological variables. To assess language parameters, the diagnostic methods of Trofymenko (2014) were used: the study of phonemic pronunciation (repetition of individual sounds, syllables, words, sentences with automated sounds), phonemic hearing (distinguishing contrasting phonemes S-Z, Sh-Zh, R-L, Ch-Ts), vocabulary (naming objects, actions, characteristics using thematic pictures), grammatical structure of speech (composition of words, coordination of parts of speech, use of prepositions) and coherent speech (translation). Neuropsychological diagnostics according to the methodology of Dehtiarenko and Pavlova (2019) included auditory attention (the ability to remember sequences of sounds, words), visual attention (finding differences in similar pictures), regulation of voluntary activity (implementation of multi-stage instructions) and the volume of auditory-verbal memory. (Appendix A, Tables A.1–A.3)

The psychological aspect was determined using standardized surveys of parents and teachers regarding the child's interest in speech therapy sessions, emotional state during remedial work, level of independence in completing tasks, number of times the child completed homework. To measure the level of inclusive interaction, structured observation was used, which was carried out in the form of free play and group

activities, and it was necessary to record the number of communicative initiatives taken by the child, the level of success in communicating with other children, the level of active participation in joint activities, and the reactions of surrounding children to the communicative efforts made by the child with speech disorders.

The study was divided into three stages: initial diagnostics of all participants, correction stage with active intervention and final diagnostics. Intermediate diagnostics were carried out six to eight weeks after the start of the intervention in order to track the dynamics and to have the opportunity to adjust individual correction paths. The data were analyzed statistically, and the SPSS Statistics 26.0 software package was used to conduct a statistical test of independent samples using the Student's t-test. Statistical significance was set at  $p < 0.05$ . To assess the effect size, Cohen's d was calculated, which made it possible to test the usefulness of the observed differences between groups.

#### 4. Results

Preliminary diagnostics established statistical homogeneity of the experimental and control groups in all speech parameters ( $p > 0.05$  for each indicator), which predetermined the validity of the subsequent comparative study of the effectiveness of the intervention. The profiles of speech disorders were similar in both groups, with most of the deficiencies related to the pronunciation of sounds, phonemic hearing and grammatical organization of speech. Six months of corrective treatment and final diagnostics showed a significant difference in the dynamics of speech development between the groups. The specific results of the comparative analysis of speech indicators are given in Table 3, which indicates the initial values, final results and statistical significance of the differences between the control and experimental groups.

**Table 3.** Comparison of speech indicators of the control and experimental groups

| Parameter                                                   | Control group<br>(n=22) | Experimental group<br>(n=23) | Statistics      |
|-------------------------------------------------------------|-------------------------|------------------------------|-----------------|
| <b>Phonetic pronunciation (number of correct sounds)</b>    |                         |                              |                 |
| <b>Before intervention</b>                                  | 12.3±2.1                | 12.5±2.0                     | t=0.32, p=0.75  |
| <b>After the intervention</b>                               | 16.4±2.0                | 19.8±1.8                     | t=5.82, p<0.001 |
| <b>Increase</b>                                             | +4.1 (+33%)             | +7.3 (+58%)                  | d=1.89          |
| <b>Phonemic hearing (% correct answers)</b>                 |                         |                              |                 |
| <b>Before intervention</b>                                  | 45.2±8.3                | 44.1±7.9                     | t=0.45, p=0.65  |
| <b>After the intervention</b>                               | 62.1±7.5                | 78.3±6.2                     | t=7.82, p<0.001 |
| <b>Increase</b>                                             | +16.9 pp (+37%)         | +34.2 pp (+78%)              | d=2.24          |
| <b>Vocabulary (number of words)</b>                         |                         |                              |                 |
| <b>Before intervention</b>                                  | 950±175                 | 940±180                      | t=0.19, p=0.85  |
| <b>After the intervention</b>                               | 1180±165                | 1410±195                     | t=4.28, p<0.001 |
| <b>Increase</b>                                             | +230 (+24%)             | +470 (+50%)                  | d=1.26          |
| <b>Grammatical correctness (% of correct forms)</b>         |                         |                              |                 |
| <b>Before intervention</b>                                  | 58.1±8.8                | 57.2±9.1                     | t=0.34, p=0.73  |
| <b>After the intervention</b>                               | 71.3±8.0                | 82.5±7.3                     | t=5.12, p<0.001 |
| <b>Increase</b>                                             | +13.2 pp (+23%)         | +25.3 pp (+44%)              | d=1.51          |
| <b>Coherent speech (average length of utterance, words)</b> |                         |                              |                 |
| <b>Before intervention</b>                                  | 3.1±0.7                 | 3.2±0.8                      | t=0.43, p=0.67  |
| <b>After the intervention</b>                               | 4.3±0.8                 | 5.8±0.9                      | t=5.67, p<0.001 |
| <b>Increase</b>                                             | +1.2 (+39%)             | +2.6 (+81%)                  | d=1.72          |

Source: compiled by the author based on Attwell et al. (2022), Tucker (2021)

Note: \*M±SD (mean ± standard deviation); pp – percentage points; d – Cohen's d (effect size)

Table 3 The experimental group scored statistically significantly lower than the control group on all single speech measures (p<0.001 after intervention for each measure). The biggest discrepancies were found in the task of phonemic awareness, since there was thirty-four percentage point improvement for the experimental group and seventeen for the control one which means almost double dynamics compared to traditional

intervention. The treatment group rate of correctly pronounced sound made an increase from twelve to twenty (12–20) phonics sounds, while the control group also made such progress by four (4) more acoustic sounds; from twelve to twenty (12–20) phonics sounds (Attwell et al., 2022). Mean effect size measured by Cohen's r was 1.26 and 2.24 for the vocabulary and phonemic awareness, which means that the

magnitude of impact of technology on oral expression development respectively was practically significant. (Appendix C)

To better understand the association between language indicators according to type of

disorder, a sub analysis was performed and the results are shown in Table 4. This study revealed some characteristics of efficiency for digital tools according to the nosological form in language disorder.

**Table 4.** Effectiveness of intervention by types of speech disorders (increase in indicators in %)

| Type of violation                         | Control group | Experimental group | Difference | Statistics      |
|-------------------------------------------|---------------|--------------------|------------|-----------------|
| <b>Phonetic-phonemic underdevelopment</b> |               |                    |            |                 |
| Number of children                        | n=9           | n=10               | –          | –               |
| Sound pronunciation                       | +35%          | +65%               | +30 pp.    | t=4.82, p<0.001 |
| Phonemic hearing                          | +42%          | +85%               | +43 pp     | t=5.23, p<0.001 |
| Average gain                              | +38.5%        | +75%               | +36.5 pp.  | d=2.15          |
| <b>Dysarthria</b>                         |               |                    |            |                 |
| Number of children                        | n=7           | n=7                | –          | –               |
| Sound pronunciation                       | +28%          | +52%               | +24 pp     | t=3.45, p=0.002 |
| Phonemic hearing                          | +35%          | +68%               | +33 pp.    | t=4.12, p<0.001 |
| Average gain                              | +31.5%        | +60%               | +28.5 pp.  | d=1.78          |
| <b>Speech Developmental Delay (SDD)</b>   |               |                    |            |                 |
| Number of children                        | n=6           | n=6                | –          | –               |
| Vocabulary                                | +26%          | +48%               | +22 pp.    | t=3.82, p=0.001 |
| Grammar                                   | +21%          | +45%               | +24 pp     | t=4.15, p<0.001 |
| Average gain                              | +23.5%        | +46.5%             | +23 pp.    | d=1.65          |

Source: systematized by the author based on Saeedi et al. (2022), Tucker (2021)

Table 4 indicates that digital resources are effective for all three types of impaired speech, but the greatest impact brought about children with phonetic-phonemic underdevelopment

change rate on average in the experimental sample was equal 75% against to 38.5% in the control group. It appears that articulation visualization programs (Articulation Station) and

real-time sound recognition (Speech Blubs) have a direct impact on the formation of phonetic/phonemic skills, as the child can see three-dimensional images of the organs of speech production and get a visual response related to proper articulation (Saeedi et al., 2022). Children with usarthria also improved markedly (60%) and least so out of the Phonetic-phonemics at the development group. What might explain this result was that they suffered from an organic motor disorder of their articulatory mechanism, which necessitated a relatively longer treatment. Among children with

language delays, vocabulary and grammar skills were notably influenced by the use of interactive digital flashcards. One of these is the Endless Alphabet app, which facilitates the multisensory processing of lexical concepts by stimulating visual, auditory, and kinesthetic elements.

To illustrate the differential dynamics of the development of major speech components, Figure 1 was produced that shows advantages of experimental impact at all levels in the speech subsystem.

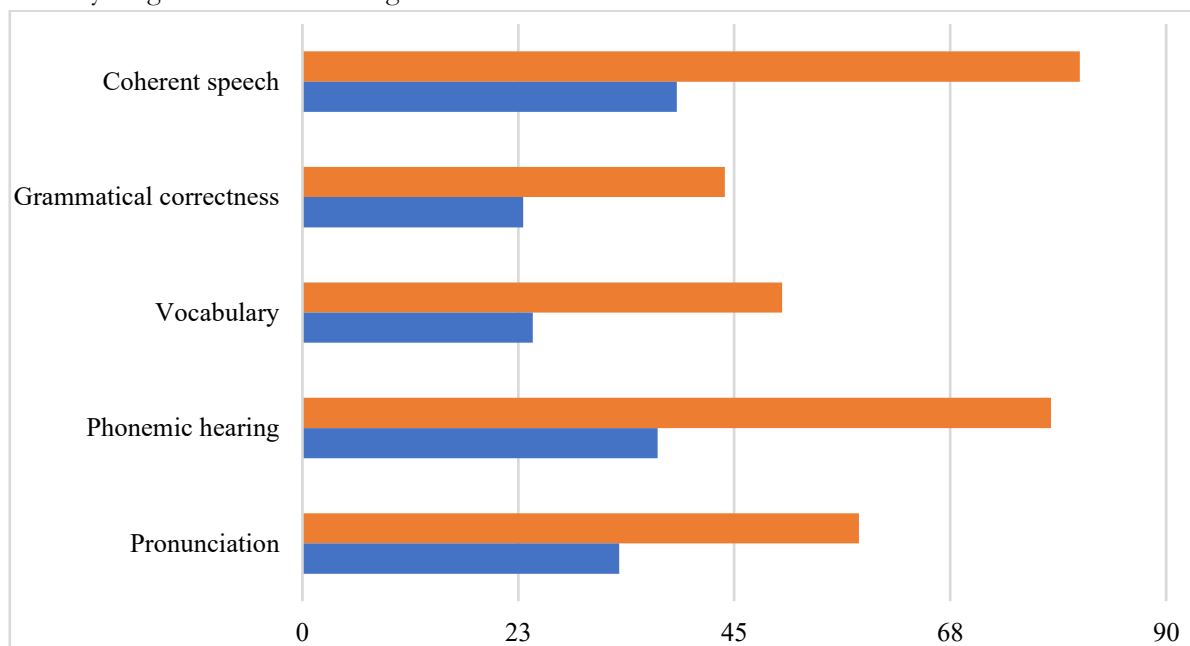


**Figure 1.** Comparison of the increase in speech indicators in the control and experimental groups, %

Source: constructed by the author based on data from Table 3

Note: \*Data are presented as percentage increase from baseline. The figure is intended to construct a bar chart with two columns (control and experimental groups) for each parameter

As shown in Figure 1, the experimental group also shows approximately twice the growth compared to the control group in all five speech parameters. The most distinctive is the development of coherent speech (81% vs. 39%) and phoneme perception (78% vs. 37%), indicating a synergistic effect of combining the traditional approach with the digital one, which provides additional motivation, interactivity and feedback. Although the difference in this issue (grammatical correctness) is minimal, the results

of the experimental group were almost twice as high as the results of the control group (44% vs. 23%), which proves the high effectiveness of digital tools in correcting the speech system of preschoolers in various aspects (Tucker, 2021).

Thus, the results of the comparative analysis of speech indicators showed a statistically and practically significant advantage of the experimental intervention based on traditional Ukrainian correction methods and digital technologies, organized on the basis of a

neuropsycholinguistic-synergistic model. For all five measured parameters (pronunciation of sounds, phonemic hearing, vocabulary, grammatical correctness, coherent speech), the experimental group demonstrated an approximately twofold increase in all indicators compared to the control group, and the effect size (Cohen's  $d = 1.26-2.24$ ) indicates the clinical significance of the use of digital technologies for the development of speech in children with various forms of speech disorders (Attwell et al., 2022; Saeedi et al., 2022; Tucker, 2021).

Psychological and cognitive parameters are crucial conditions for the success of speech therapy correction, since the success of assimilating new information and mastering

language skills directly depends on the child's motivation, his ability to focus on the process of learning new material and good mood. The results of the study showed that the experimental and control groups had significantly different dynamics of improvement in psychological indicators, which is explained by the gamification of digital tools, visualization of progress and the reward system, which increased the intrinsic motivation of children to daily speech therapy exercises. The comprehensive results of the assessment of neuropsychological and motivational parameters are presented in Table 5, which demonstrates statistically significant differences between the groups after six months of intervention.

**Table 5.** Comparison of neuropsychological and motivational indicators

| Parameter                                                      | Control group (n=22) | Experimental group (n=23) | Statistics        |
|----------------------------------------------------------------|----------------------|---------------------------|-------------------|
| <b>Motivation level (scale 1-10 points)</b>                    |                      |                           |                   |
| Before intervention                                            | 3.2±0.8              | 3.1±0.9                   | $t=0.38, p=0.70$  |
| After the intervention                                         | 3.6±0.9              | 5.8±0.7                   | $t=9.12, p<0.001$ |
| Increase                                                       | +0.4 (+12%)          | +2.7 (+87%)               | $d=3.12$          |
| <b>Attention span on task (minutes)</b>                        |                      |                           |                   |
| Before intervention                                            | 8.0±2.0              | 8.2±2.1                   | $t=0.32, p=0.75$  |
| After the intervention                                         | 10.1±1.9             | 13.4±1.8                  | $t=6.18, p<0.001$ |
| Increase                                                       | +2.1 (+26%)          | +5.2 (+63%)               | $d=1.88$          |
| <b>Emotional state (% of positive reactions)</b>               |                      |                           |                   |
| Before intervention                                            | 52.3±11.2            | 51.8±10.8                 | $t=0.15, p=0.88$  |
| After the intervention                                         | 62.1±9.5             | 85.3±8.2                  | $t=8.92, p<0.001$ |
| Increase                                                       | +9.8 pp (+19%)       | +33.5 pp (+65%)           | $d=2.61$          |
| <b>Independence in performing exercises (scale 1-5 points)</b> |                      |                           |                   |
| Before intervention                                            | 2.1±0.7              | 2.0±0.8                   | $t=0.43, p=0.67$  |
| After the intervention                                         | 2.8±0.6              | 4.2±0.5                   | $t=8.45, p<0.001$ |
| Increase                                                       | +0.7 (+33%)          | +2.2 (+110%)              | $d=2.58$          |
| <b>Frequency of home practice (times/week)</b>                 |                      |                           |                   |

|                               |             |              |                  |
|-------------------------------|-------------|--------------|------------------|
| <b>Before intervention</b>    | 1.8±1.1     | 1.9±1.2      | t=0.28, p=0.78   |
| <b>After the intervention</b> | 2.1±1.2     | 6.2±0.8      | t=13.45, p<0.001 |
| <b>Increase</b>               | +0.3 (+17%) | +4.3 (+226%) | d=4.02           |

Source: Compiled by the author based on Kearney & Guenther (2019), Wang et al. (2022)

Note: \*M±SD (mean ± standard deviation); pp – percentage points; d – Cohen’s d (effect size). Motivation and independence were assessed using questionnaires from parents and educators; emotional state was recorded during structured observation in classes As can be seen in table 5, the differences between groups were most pronounced for motivation and frequency of homework. The experimental group received 3.1±0.9 to 5.8±0.7 on a scale of ten-point motivation score, which was higher by 87% than in the control group (between 3.2±0.8 and 3.6±0.9 points), figure that represents an increase also by 87%. The size of the effect concerning this variable was d=3.12, very large and concluding about a big impact of gaming digital tools over the intrinsic motivation in preschoolers’. Parents of children in the experimental group observed their child initiating requests to “play speech therapy games” with him/her and cooperatively completing home assignments using a mobile app, whereas parents in the control group were repeatedly heard say that they could not get their child to do homework. The experimental group performed home exercise > 1.9±1.2 times/week, > threefold increase (6.2±0.8 items/week) than control, and the cumulative corrective efficacy

of SEC was much greater than control in which frequency was unaltered (Wang et al., 2022).

There was also a significant difference in the length of attention voluntarily given to the SLP’s task. The attention span of the experimental group children increased from 8.2±2.1 to 13.4±1.8min (63%), while that of the control group children showed only a 26% increase (from 8.0±2.0 to 10.1±1.9 minutes). This is because interactive computer games with stimuli that changed dynamically, moving life-like characters and sound extras were more attractive to children than are the traditional game cards and mirrors. Neuroplastic mechanisms, as described by Kearney and Guenther (2019), also confirmed that neural networks for planning motor speech develop more quickly and stronger when exercises are made with direct multisensory feedback from auditory and visual signal (and it should be correlated to a stable attention and an active participation of the child in the correction).

To explore motivation dynamics in more detail three measurements were taken at one of the points of measurement within the corresponding study phases (initial diagnostics, mid-diagnosis after 6-8 weeks and final diagnosis), which allows comparisons of motivational reactions (see Table 6 and Figure 2).

**Table 6.** Dynamics of motivation level during the study (scores on a scale of 1–10)

| <b>Group</b>                   | <b>September 2024<br/>(beginning)</b> | <b>November 2024<br/>(interim)</b> | <b>February 2025<br/>(end)</b> | <b>Total gain</b> |
|--------------------------------|---------------------------------------|------------------------------------|--------------------------------|-------------------|
| <b>Control (n=22)</b>          | 3.2±0.8                               | 3.4±0.8                            | 3.6±0.9                        | +0.4 (+12%)       |
| <b>Experimental<br/>(n=23)</b> | 3.1±0.9                               | 4.6±0.8                            | 5.8±0.7                        | +2.7 (+87%)       |
| <b>Statistics</b>              | t=0.38, p=0.70                        | t=5.12, p<0.001                    | t=9.12, p<0.001                | d=3.12            |

Source: constructed by the author based on Wang et al. (2022) Note: \*Statistics reflect comparisons between groups at each measurement point

The difference in the trajectories of motivation change in the two groups is fundamentally different, as shown in Table 6. The control group gradually increases linearly (from 3.2 to 3.6 points), while the experimental group increases exponentially, with the highest increase at the beginning (from 3.1 to 4.6 points) and leveling off

(5.8 points). Intermediate diagnostics showed that there is a statistically significant difference between the groups ( $t= 5.12$ ,  $p<0.001$ ), which confirms the pace of the impact of gaming applications on children's psychological involvement. These trajectories are visualized in Figure 2.

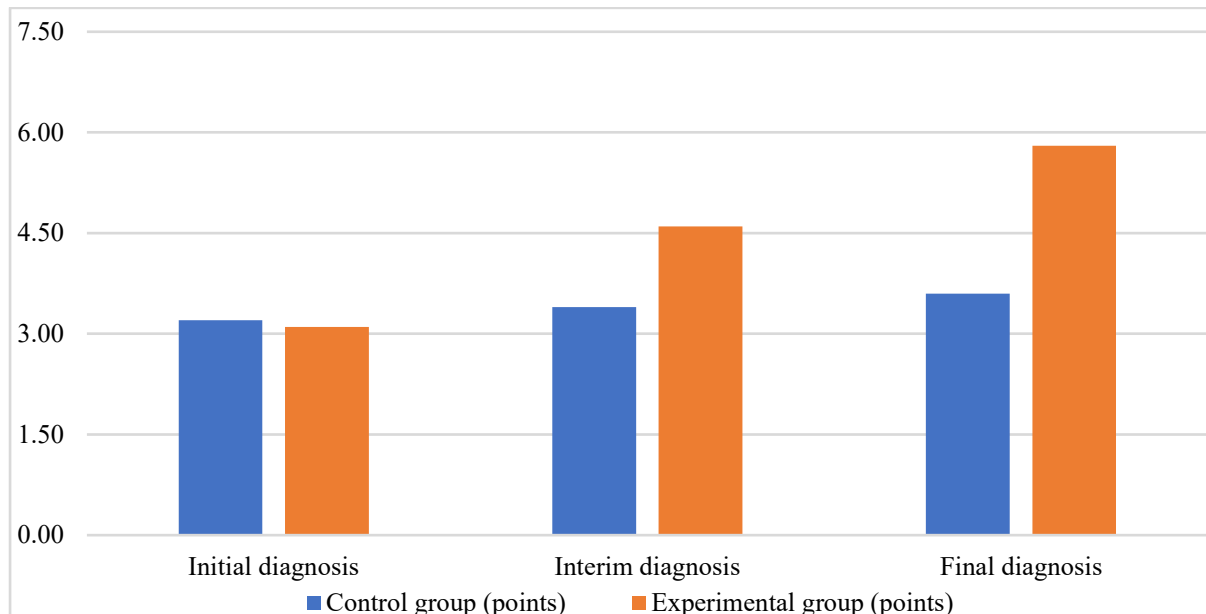


**Figure 2.** Trajectory of change in motivation level during the 6 months of the study

Source: constructed by the author based on data from Table 6

The differences in changes in motivation trajectories between the two groups are clearly demonstrated in Figure 2. The control group has a slow linear growth with the small grade (from 3.2 to 3.6 points in six months), while the experimental group shows an exponential growth curve, reaching very high values already within two months from the start of implementation (from 3.1 to 4.6 points), and further stabilizing at an extremely high level afterwards (5.8 points). Initial diagnostics indicated that after two months of using digital tools, the motivation to learn in the experimental group was significantly higher than motivation in the control group ( $t=5.12$ ,  $p<0.001$ ), which is evidence for a quickly formed effect of gaming applications on children's psychological involvement in remediation.

Therefore, analysis results of neuropsychological and motivational indicators showed that introduction of digital tools into traditional

methods of ST helps increase significantly the psychological factors for effective correction. The strongest impact was found for homework frequency ( $d=4.02$ ) and motivation level ( $d=3.12$ ), demonstrating that maintaining stable internal motivation to perform daily exercises can be realized through a game system with immediate feedback and progress visualization (Kearney & Guenther, 2019; Wang et al., 2022). Favourable conditions for neuroplastic events aimed at the formation of new skills in speech pathologies at preschool age are created by means of enhancing attention, emotional reactions, and independence.

The level of communicative abilities of the children who have completed their speech therapy in the inclusive education and being able to efficiently implement it when interacting with their peers as well as group work and free play are one of the significant success factors for correction of children attending speech therapy

in a common collective. They found a significant difference in measure of social inclusion for the experimental rather than control group with the greatest differences seen in functional communication and child initiative in interaction. Three children from the experimental group, each non-verbal, were provided with an AAC communicators (Grid 3 and Proloquo2Go) enabling them to communicate through

alternative pictures (= pictograms) together with speech generation. This method transformed their role in the group dynamic and they are now able to be active participants in socialising. Detailed outcomes of the evaluation based on inclusive interaction are shown in Table 7 from which it is seen that significant differences exist among the groups throughout the six months intervention.

**Table 7.** Comparison of inclusive interaction indicators

| Parameter                                                                   | Control group (n=22) | Experimental group (n=23) | Statistics      |
|-----------------------------------------------------------------------------|----------------------|---------------------------|-----------------|
| <b>Number of spontaneous communicative acts (per 30 min of observation)</b> |                      |                           |                 |
| Before intervention                                                         | 4.1±1.7              | 4.3±1.8                   | t=0.38, p=0.70  |
| After the intervention                                                      | 6.8±1.9              | 11.7±2.1                  | t=8.34, p<0.001 |
| Increase                                                                    | +2.7 (+66%)          | +7.4 (+172%)              | d=2.45          |
| <b>Initiative in group play (scale 1–10 points)</b>                         |                      |                           |                 |
| Before intervention                                                         | 3.7±1.1              | 3.8±1.2                   | t=0.29, p=0.77  |
| After the intervention                                                      | 5.2±1.3              | 7.9±1.0                   | t=7.82, p<0.001 |
| Increase                                                                    | +1.5 (+41%)          | +4.1 (+108%)              | d=2.29          |
| <b>Peer speech comprehension (% of successful communications)</b>           |                      |                           |                 |
| Before intervention                                                         | 37.9±11.8            | 38.5±12.3                 | t=0.17, p=0.87  |
| After the intervention                                                      | 58.3±10.5            | 76.8±9.2                  | t=6.45, p<0.001 |
| Increase                                                                    | +20.4 pp (+54%)      | +38.3 pp (+99%)           | d=1.92          |
| <b>Participation in group classes (% active participation)</b>              |                      |                           |                 |
| Before intervention                                                         | 42.5±13.2            | 41.8±12.8                 | t=0.18, p=0.86  |
| After the intervention                                                      | 61.2±11.5            | 83.5±9.8                  | t=7.23, p<0.001 |
| Increase                                                                    | +18.7 pp (+44%)      | +41.7 pp (+100%)          | d=2.15          |
| <b>Sociometric status in the group (peer selection scores)</b>              |                      |                           |                 |
| Before intervention                                                         | 2.3±1.1              | 2.2±1.0                   | t=0.31, p=0.76  |
| After the intervention                                                      | 3.8±1.2              | 5.9±1.1                   | t=6.12, p<0.001 |
| Increase                                                                    | +1.5 (+65%)          | +3.7 (+168%)              | d=1.88          |

Source: Compiled by the author based on Kadis et al. (2014), Wang et al. (2022)

Note: \*M $\pm$ SD (mean  $\pm$  standard deviation); pp – percentage points; d – Cohen's d (effect size). Indicators were recorded during structured observation of free play and group activities; sociometric status was determined by the paired choice method

The inclusive interaction indicators as shown in Table 7, showed that there was two-time increase for the experimental group. The largest improvements were observed for spontaneous communicative acts, which increased by 172% (from  $4.3\pm1.8$  to  $11.7\pm2.1$  acts) relative (%) compared to the control group (66%), that is, the frequency of communication with classmates approximately tripled. Initiative in group games improved by 108% ( $3.8\pm1.2$  to  $7.9\pm1.0$  points), which meant that the achievement of children becoming more active performers of task roles in a group significantly increased (Kadis et al., 2014).

The findings of the three non-verbal participants in the experimental group, who all utilised the Grid 3 and Proloquo2Go ACC communications devices, are especially noteworthy. Outcomes of this evolution are illustrated in Table 8, and bear witness to the transformative effect of alternative communication on young children's socialization when they had previously been marginalized from group communication in virtual terms by virtue of being unable to express their needs and wants.

**Table 8.** Results of using AAC communicators by nonverbal children (n=3)

| Parameter                                               | Before intervention | After the intervention | Increase         |
|---------------------------------------------------------|---------------------|------------------------|------------------|
| <b>Means of communication</b>                           |                     |                        |                  |
| <b>Verbal communication (%)</b>                         | 0                   | 0                      | –                |
| <b>Gestures and pointing (%)</b>                        | $78.5\pm12.3$       | $35.2\pm8.5$           | -43.3 pp.        |
| <b>AAC communicator (%)</b>                             | 0                   | $43.2\pm5.8$           | +43.2 pp.        |
| <b>Vocalizations without words (%)</b>                  | $21.5\pm7.2$        | $21.6\pm6.9$           | +0.1 pp.         |
| <b>Communication effectiveness</b>                      |                     |                        |                  |
| <b>Successful communicative acts (%)</b>                | $32.8\pm9.5$        | $71.5\pm7.2$           | +38.7 pp (+118%) |
| <b>Peer understanding of message (%)</b>                | $28.3\pm11.2$       | $68.9\pm9.3$           | +40.6 pp (+143%) |
| <b>Message transmission speed (seconds)</b>             | $45.2\pm12.8$       | $8.3\pm2.1$            | -36.9 sec (-82%) |
| <b>Social integration</b>                               |                     |                        |                  |
| <b>Communication initiation (once every 30 minutes)</b> | $1.2\pm0.8$         | $5.8\pm1.3$            | +4.6 (+383%)     |
| <b>Responses to peer appeals (%)</b>                    | $35.7\pm13.5$       | $82.4\pm8.7$           | +46.7 pp (+131%) |
| <b>Participation in group play (% of time)</b>          | $18.5\pm9.8$        | $62.3\pm11.2$          | +43.8 pp (+237%) |
| <b>Positive emotions during communication (%)</b>       | $41.2\pm15.3$       | $89.6\pm7.5$           | +48.4 pp (+117%) |
| <b>Using icons</b>                                      |                     |                        |                  |

|                                           |   |          |   |
|-------------------------------------------|---|----------|---|
| <b>Number of icons mastered</b>           | – | 127±23   | – |
| <b>Average icon search time (seconds)</b> | – | 3.8±1.2  | – |
| <b>Icon selection accuracy (%)</b>        | – | 91.5±4.3 | – |

Source: Systematized by the author based on Kadis et al. (2014)

Note: \*data are presented in M±SD format; pp – percentage points. AAC communicators: Grid 3 (n=2) and Proloquo2Go (n=1) with individually selected icon sets (80–150 symbols per child). Observations were conducted during free play and structured group activities

Table 8 shows the radical change in the communication profile of nonverbal children after the introduction of ACC technologies. Before the intervention, these children used gestures (78.5%) and voice signals (21.5%) with the lowest level of communication success (32.8%), as their peers did not understand their messages. After the systematic use of ACC communicators, a higher level of success was recorded (71.55), and the speed of message transmission decreased (from 45 to 8 seconds), which brought the speed of ACC communication

closer to natural conversation. It was found that the number of communication initiatives increased fourfold (from 1.2±0.8 to 5.8±1.3 times), and the proportion of time spent in group games increased to 62.3% of the observation time, indicating effective social integration of children who were previously isolated.

Figure 3 provides a visualization of the comparative dynamics of inclusive interaction, which clearly illustrates the benefits of experimental intervention in the development of social and communication skills in children with speech disorders in an inclusive environment.

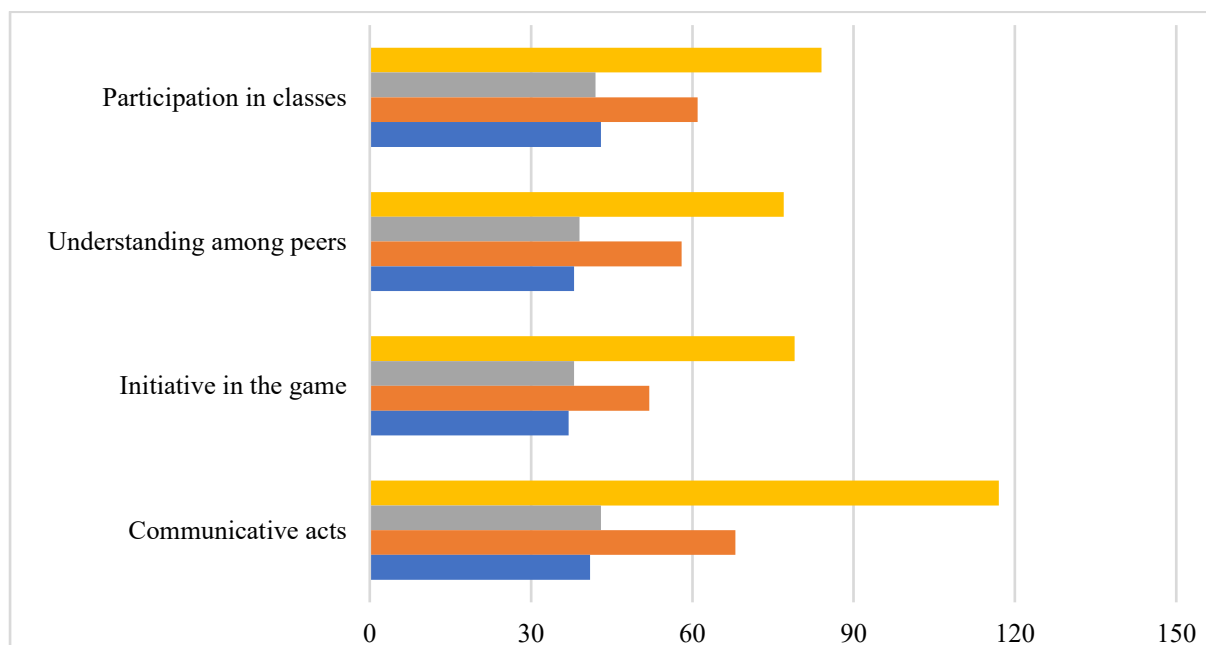


**Figure 3.** Comparison of the level of inclusive interaction (% of the maximum level)

Source: constructed by the author based on data from Table 7

Therefore, a qualitative transformation of the social and communicative activity of children with speech disturbances in inclusive setting was achievable through experimental intervention

with digital tools communicators of AAC. Three children who have not been active communication partners re-entered class when

the full-offset system was applied (Kadis et al., 2014; Wang et al., 2022).

The study results showed statistically significant improvement of the experimental in all parameters: sounds (+58% vs +33%), phonemic hearing (+78% vs. +37%), vocabulary (+50% vs +24%), grammatically correct speech (+44% vs +23%), motivation to learn and develop creative work competences, inclusive interaction with computer assistants for autistic children ( $87 \pm 12$  versus  $172 \pm 66$ ). Effect size ( $d=1.26-4.02$ ) reveals a large practical importance of intervention. The possibility of implementing the neuropsycholinguistic-synergistic approach (Danilavichiutė, 2024) in practice of organizing speech therapy support for children in inclusive environment was confirmed. The table shows all indicators for which results of further statistical analysis are presented and provided in Appendix C.4.

## 5. Discussion

The findings of the present study are indicative that the use of both digital tools and touch-and-feel methods in a combined manner is significantly beneficial for remediating speech disarray with preschool children that lie in an integrated environment. In the experimental group, all of speech and psychological indices increased much more than in comparison with those in control one so that the above results are described by effectiveness of neuropsycholinguistic – synergistic method for organization speech therapy (Danilavichiutė A., 2024). The results are consistent with the scientific evidence from international studies on the effectiveness of digital technologies in developing speech therapy and enrich the scientific knowledge base about mechanisms of influence of such means upon a speech system at different levels.

The large increase in speech quality (+58% experimental group; +33% control group) at the neurological level corresponds to findings from neuro-imaging studies that show changes in brain

structure and function after application of intensive speech therapy. According to Kadis et al. (2014) the cortical thinning in Wernicke's area resulting from neuropruning (second mechanism of neuroplasticity) is observed in children with Apraxia of Speech after intensive PROMPT therapy. Boliek et al. (2017) reported that functional and structural changes of activity in a child with cerebral palsy could be obtained following Lee Silverman Voice Treatment LOUD voice therapy, which persisted from the end to twelve weeks after treatment.

In our study, we enrich these findings with the evidence that visual (Articulation Station) and immediate responses (Speech Blubs) could prompt neuroplastic changes in children thanks to multisensory stimulation provided by devices and due to the awareness regarding individual articulatory movements of their oral cavity. The neurophysiology of speech motor planning (Kearney & Guenther, 2019) ideally involves integration of sensory feedback with motor control which can be supported by the validity of digital tools that offer brief visual and auditory feedback on articulatory quality. Wang et al. (2022) demonstrated more rapid shaping of speech-generating neural networks with multisensory stimulation based on repetitive motor practice, in line with our results regarding the fast change in the experimental group during the first 2 months. Badawi et al. (2018) provided the first (magnetoencephalography based) objective neurophysiological evidence for altered neural activity patterns in motor language areas following intensive treatment.

On a psychological level, the largest difference was that motivation increased by 87% in the treatment group vs. 12% in the control and, as a consequence, homework completion was three times higher. This is in line with Morgan's (2020) perspective that the integration of neurobiology knowledge into therapeutic speech practice can actually be used to build better treatment protocols which also consider cognitive and affective aspects involved in successful correction. The role of visual aids and immediate feedback in the enhancement of attention and

motivation among preschoolers was once again supported by Kurienkova (2023b) who demonstrated the efficiency of visualization methods for working with children affected to a high degree by speech disorders. Galushchenko, Bohdanov (2023) explained that the methods of stimulating speech-motor activity in children are used, and for sustainable development of speech skills it is important to have emotional involvement (this fact fully complies with our data about a high percentage of positive emotional reactions - 85%) when working using digital tools. This is also the key new finding of our study: that gamification -having a point, levels and progress visualisation system- competitive to intrinsic motivation is enduring, and it lasts over even six months of intervention.

At the language level, it is worth noting substantial gains in vocabulary (+50% vs. +24%) and grammatical accuracy (+44% vs. +23%), correlated with Pavlova's (2017) observations, who demonstrated that innovative technologies have proved effective tools for creating communicative activities among preschool nonverbal children through principles of multisensorial stimulation and interactivity. Kliap et al. (2023) stated that what is required is a method of dealing with the child who exhibits developmental language delay at various ages, and it is our contention that this must be an integrated approach to all aspects of the language system. We extend these findings and suggest that digital flashcards with native speaker voiceover in addition to interactive games, like Endless Alphabet, promotes acquisition of lexical and grammatical knowledge more than paper flashcards because the multimodal representation of input is both accessible and infinitely repeatable.

Our contribution is most significant as we empirically prove that there is synergistic effect of applying all 4 levels of correcting effects (neuro-, psycho-linguistic and S) to an intervention system. One of the most powerful synergistic effects occurred in the measures related to inclusive interaction (spontaneous communication acts): there was an increase of

172% in spontaneous communicative acts for EG (Table V). This is in agreement with Sutherland et al. (2018) We positively assessed the results of telemedicine in ensuring speech therapy for autistic children we know that the presence of therapeutic tools plays a fundamental role in integrating children into life . Hadaya, Voniati An article by Hadaya and Voniati (2020) discusses that digital tools need to be co-developed for relevance to speech therapy practice as well, but the authors suggest doing so in consideration of peoples' cultural backgrounds and differences. As our analysis has demonstrated the adaptation of digital tools to the specific nature of Ukrainian language and classification of AAC communicators in group with nonverbal children permitting three participants out of otherwise excluded from social contacts to get 43% successful communicative acts is vital for inclusive environment in Ukraine.

One of significant applied aspects is the reporting on availability of digital tools for independent use at home which would be especially relevant taking into account the limited resources of speech therapy services in Ukraine. The study by Fong et al. (2021) it was reported that teletherapy for speech therapy was effective, and could be used during "times of crisis" such as the COVID-19 pandemic. Mykhailenko (2022) also stressed the role of online resources and mobile apps for compensating the work with children having complex floral disorders under conditions of either geographical or financial unavailability of specialized services. Since, the following article is built on these results, which links parental monitoring through a mobile application doubles and subsequently triples the frequency of corrective action; hence cumulatively increases beyond what can be achieved by simply meeting twice per week in person.

Thus, our study contributes to clearing the way in which a digital tool functions as part of speech therapy for children with speech disorders by empirically confirming the neuropsycholinguistic-synergistic model for

organizing support in inclusive conditions and demonstrates its feasibility in Ukrainian practice.

## 6. Conclusions

The paper proved an empiric justification for the use of digital tools in children of preschool age with speech disorders under conditions of inclusive education as a combination of traditional national futuristic approach to work based on principles of neuropsycholinguistics-synergetics model by Danilavichiutė (2024). A trial with 45 children aged 5–7 years showed that the experimental intervention was better than control according to all outcomes.

It was established that combining the traditional methods and digital technologies will make it possible to double the increase in speech rate. Results indicated that the experimental group improved 58 percent in pronunciation, 78 percent in phonemic hearing, and a 50 percent in vocabulary acquisition and control comparison exhibited a 33% improvement on pronunciation, 37 % on phonemic hearing, and 24 % on vocabulary. The effect size was between  $d=1.26$  and  $d=4.02$ , respectively proving the strong practical value of the intervention.

The strongest effects were for psychological outcomes; motivation increased 87% ( $d=3.12$ ) and the amount of home practice completed more than tripled ( $d=4.02$ ). This supports the

fact that immediate feedback systems integrate gameplay elements and hence can provoke internal motivation for practising more intensively. Synergistic evidence for the incorporation of all four levels of corrective influence was obtained: the main effect indicators increased by 172. All non-verbal children had a success rate of 43%, thanks to the AAC communicators, that ensured their real social inclusion.

The practical significance of the research is to develop specific model how to integrate ten digital resources into traditional Ukrainian practice and give advices considering how often they should be used and parents' role. As we concluded, digital tools do not substitute classic ways, but they assist the therapist as prime actor in the corrective action.

Areas of potential future research further investigations in a larger sample are needed with randomised clinical trial design for more than 12 months, differentiated efficacy within different nosological forms of the disorder, development of Ukrainian-language mobile applications for speech and language therapy as a part of telehealth cognitive services including tDCS-based neurobiology CBLP approaches, planned repeatable neuroimaging studies to objectively confirm neural plastic changes and combined treatment format based on telerehabilitation.

## References

- Attwell, G. A., Bennin, K. E., & Tekinerdogan, B. (2022). A systematic review of online speech therapy systems for intervention in childhood speech communication disorders. *Sensors*, 22(24), 9713. <https://doi.org/10.3390/s22249713>
- Badawi, N., Gudziol, V., Sirsi, D., Namasivayam, A., Pukonen, M., Kroll, R., & Pang, E. W. (2018). Impact of motor speech intervention on neural activity in children with speech sound disorders: Use of magnetoencephalography. *Journal of Behavioral and Brain Science*, 8(7), 415–429. <https://www.scirp.org/journal/paperinformation?paperid=85823>
- Boliek, C. A., Fox, C. M., Bakhtiari, R., Cummine, J., Newman, D. S., Halpern, A., & Doan, D. (2017). Changes in brain structure and function following intensive voice training (LSVT LOUD®) in children with cerebral palsy and motor speech disorders. *Human Brain Mapping*, 38(11), 5303–5321. <https://doi.org/10.1002/hbm.23669>
- Chernychenko, L. I. (2024). Information and digital competence of teachers and lecturers as a modern requirement for the development of the digital society. *Education. Innovation. Practice*, 4, 45–52. <https://oip-journal.org/index.php/oip/article/view/535>

- Danilavichiutė, E. (2024). Current neuro-psycho-linguistic-synergetic foundations of the organization of speech therapy for people with special speech needs (the concept of neurolinguistics). *Special Education: Teaching and Education*, 116(4), 8–29. <https://doi.org/10.33189/ectu.v116i4.193>
- Danilavichiutė, E. A. (2021). Innovative concept of defining functional and speech educational difficulties in children with special needs. In *Children with special needs: From equal rights to equal opportunities* (pp. 47–55). Kyiv. <https://lib.iitta.gov.ua/id/eprint/728928>
- Dehtiarenko, T. V., & Pavlova, N. V. (2019). Actuality of interdisciplinary and neuropsychological approaches to the diagnosis of severe speech disorders in early childhood. *Nauka i Osvita*, 8, 30–37. <http://dspace.pdpu.edu.ua/handle/123456789/3771>
- Fong, R., Tsai, C.-F., & Yiu, O. Y. (2021). The implementation of telepractice in speech-language pathology in Hong Kong during the COVID-19 pandemic. *Telemedicine and e-Health*, 27(1), 30–38. <https://doi.org/10.1089/tmj.2020.0223>
- Galushchenko, V. I., & Bohdanov, O. O. (2023). Use of attractive stimulation of motor activity of a child with TPM. *Problems of Rehabilitation: Collection of Scientific Works*. <http://dspace.pdpu.edu.ua/handle/123456789/18235>
- Hadaya, L., & Voniati, L. (2020). Co-designing digital tools to enhance speech and language therapy training in Ghana. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–13). <https://doi.org/10.1145/3313831.3376474>
- Saeedi, S., Bouraghi, H., Seifpanahi, M.-S., & Ghazisaeedi, M. (2022). Application of digital games for speech therapy in children: A systematic review of features and challenges. *Journal of Healthcare Engineering*, 2022, Article 4814945. <https://doi.org/10.1155/2022/4814945>
- Kabelnikova, N. V., & Savinova, N. V. (2024). Use of digital technologies in speech therapy for children with hearing impairments. *Scientific Papers. Series: Pedagogical Sciences*, 216, 293–299. <https://doi.org/10.36550/2415-7988-2024-1-216-293-299>
- Kadis, D. S., Goshulak, D., Namasivayam, A., Pukonen, M., Kroll, R., De Nil, L. F., & Lerch, J. P. (2014). Cortical thickness in children receiving intensive therapy for idiopathic apraxia of speech. *Brain Topography*, 27(2), 240–247. <https://doi.org/10.1007/s10548-013-0308-8>
- Kearney, E., & Guenther, F. H. (2019). Articulating: The neural mechanisms of speech production. *Language, Cognition and Neuroscience*, 34(9), 1214–1229. <https://doi.org/10.1080/23273798.2019.1589541>
- Kliap, M. I., Lukianyk, L. V., & Kravets, N. P. (2023). Ways to overcome general speech underdevelopment in preschool and primary school children and children with autism. *Innovatsiina Pedagogika*, 62(1), 71–74. <https://dspace.uzhnu.edu.ua/jspui/handle/lib/61755>
- Kolomoiets, T. H. (2023). Use of digital technologies in speech therapy. *Scientific Hours of the NPU Named after M. P. Drahomanova. Series 19: Correctional Pedagogy and Special Psychology*, 44, 17–23. <http://enpuir.npu.edu.ua/handle/123456789/41785>
- Korobeinykova, T. S. (2025). Psycholinguistic approach to diagnosis and correction of optical dyslexia and dysgraphia. *Scientific Journal of the Mykhaila Drahomanova UDU. Series 19*, 48, 70–74. <https://enpuir.udu.edu.ua/handle/123456789/49691>
- Kurienkova, A. V. (2023a). Innovations in speech development technology for children with ZNM in the work of a speech therapist. *Current Issues of Humanities*, 62(2), 248–254. <https://doi.org/10.24919/2308-4863/62-2-40>
- Kurienkova, A. V. (2023b). Using visualization methods in working with children with severe movement disorders. *Inclusion and Diversity*, 30–33. <https://doi.org/10.32782/inclusion/2023.spec.6>
- Lopatynska, N. A. (2020). Neurostimulation technologies in speech therapy practice for preschool children with severe movement disorders. *International Journal of Innovative Technologies in Social Science*, 3(24), 3–11. [https://doi.org/10.31435/rsglobal\\_ijitss/31032020/7011](https://doi.org/10.31435/rsglobal_ijitss/31032020/7011)
- Madigan, S., Browne, D., Racine, N., Mori, C., & Tough, S. (2021). Association between screen time and children's performance on a developmental screening test. *JAMA Pediatrics*, 173(3), 244–250. <https://doi.org/10.1001/jamapediatrics.2018.5056>

- Mykhailenko, O. (2022). The use of online resources and mobile applications in correctional work with students with combined hearing and intellectual disabilities. *Special Education: Education and Upbringing*, 105(1), 67–75. <https://doi.org/10.33189/ectu.v1i105.96>
- Morgan, A. (2020). Speech-language pathology and neuroscience: Advancing clinical practice through science. *International Journal of Speech-Language Pathology*, 22(6), 572–581. <https://doi.org/10.3109/17549507.2013.777786>
- Olkhovska, I. P. (2021). Use of innovative technologies in the formation of communicative speech in children with severe speech disorders. In *International Scientific Conference*. <https://doi.org/10.30525/978-9934-26-173-2-56>
- Pavlova, N. V. (2017). *Formation of communicative activity in non-verbal children of early preschool age using innovative technologies* (Doctoral dissertation). <http://dspace.pdpu.edu.ua/handle/123456789/694>
- Ribtsun, Yu. V. (2011). Characteristics of phonetic-phonematic syllable movement of a five-year-old child with phonetic-phonemic underdevelopment. *Ukrainian Journal of Neurology*, 2, 36–53. <https://lib.iitta.gov.ua/id/eprint/5832>
- Ribtsun, Yu. V. (2012). *Correction of speech development of a five-year-old child with phonetic-phonematic speech underdevelopment: Program-methodical complex*. Kyiv. <https://lib.iitta.gov.ua/id/eprint/5812>
- Sukhoviiienko, N. (2025). Theory of movement and motor activity as a psychological basis of speech therapy. *Scientific Works of MAUP: Pedagogical Sciences*, (3), Article 12. <https://doi.org/10.32689/maup.ped.2025.3.12>
- Sutherland, R., Trembath, D., & Roberts, J. (2018). Telehealth and autism: A systematic review of speech-language pathology services. *International Journal of Speech-Language Pathology*, 20(3), 324–336. <https://doi.org/10.1080/17549507.2018.1465123>
- Tarasun, V. V. (2017). *Fundamentals of the theory and practice of logodydaktyka*. Karavela. <http://enpuir.npu.edu.ua/handle/123456789/23345>
- Trofymenko, L. I. (2014). *Diagnostics and correction of general speech underdevelopment in preschool children*. Publishing House of the National Pedagogical University named after M. P. Drahomanova. <https://lib.iitta.gov.ua/id/eprint/8723>
- Tucker, J. K. (2021). Digital tools in pediatric speech therapy: Enhancing traditional methods. *Journal of Communication Disorders*, 93, 106139. <https://doi.org/10.1016/j.jcomdis.2021.106139>
- Wang, Y., Ji, Q., Zhou, C., & Wang, Y. (2022). Brain mechanisms linking language processing and motor skill training: Implications for neurological speech therapy. *Frontiers in Human Neuroscience*, 16, Article 911894. <https://doi.org/10.3389/fnhum.2022.911894>

## 8. Author Declaration

The authors confirm that this manuscript is an original work, has not been previously published, and is not under consideration for publication elsewhere. All sources, ideas, and materials used in the preparation of this article have been appropriately cited in accordance with academic standards.

The authors declare that there are no conflicts of interest, financial or otherwise, that could have influenced the research design, data collection, analysis, interpretation, or the presentation of the findings.

## Appendix A

### Diagnostic tools

**Table A.1.** Speech sound assessment form

Child's full name: \_\_\_\_\_ Age: \_\_\_\_\_ Date: \_\_\_\_\_

| Sound | Word     | Result                                                   | Sound | Word    | Result                                                   |
|-------|----------|----------------------------------------------------------|-------|---------|----------------------------------------------------------|
| [C]   | coat     | <input type="checkbox"/> N <input type="checkbox"/> por. | [S]   | sleigh  | <input type="checkbox"/> N <input type="checkbox"/> por. |
| [B]   | banana   | <input type="checkbox"/> N <input type="checkbox"/> por. | [R]   | rabbits | <input type="checkbox"/> N <input type="checkbox"/> pair |
| [C]   | cake     | <input type="checkbox"/> N <input type="checkbox"/> pair | [S]   | sugar   | <input type="checkbox"/> N <input type="checkbox"/> p.   |
| [H]   | house    | <input type="checkbox"/> N <input type="checkbox"/> por. | [H]   | hat     | <input type="checkbox"/> N <input type="checkbox"/> pair |
| [D]   | duck     | <input type="checkbox"/> N <input type="checkbox"/> pair | [F]   | frog    | <input type="checkbox"/> N <input type="checkbox"/> por. |
| [M]   | mountain | <input type="checkbox"/> N <input type="checkbox"/> cf.  | [C]   | cup     | <input type="checkbox"/> N <input type="checkbox"/> p.   |
| [A]   | apron    | <input type="checkbox"/> N <input type="checkbox"/> pair | [P]   | pike    | <input type="checkbox"/> N <input type="checkbox"/> por. |
| [W]   | water    | <input type="checkbox"/> N <input type="checkbox"/> por. | [P]   | cancer  | <input type="checkbox"/> N <input type="checkbox"/> por. |
| [M]   | mom      | <input type="checkbox"/> N <input type="checkbox"/> por. | [L]   | paw     | <input type="checkbox"/> N <input type="checkbox"/> pair |

Total number of correct sounds: \_\_\_\_\_ / 31

Source: Trofymenko (2014)

**Table A.2.** Phonemic hearing test

Instructions: Clap when you hear the sound [C]

| Sound spoken     | S                        | Z                        | SH                       | S                        | TS                       | S                        | ZH                       | S                        | T                        | S                        |
|------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Child's reaction | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Correct answers: \_\_\_\_\_ / 10 = \_\_\_\_\_ %

Source: Trofymenko (2014)

**Table A.3.** Motivation questionnaire (for parents)

Scale 1-10: 1=not at all, 10=completely

| Statement                                                | Points |
|----------------------------------------------------------|--------|
| <b>The child happily attends speech therapy sessions</b> | —      |
| <b>The child willingly does their homework</b>           | —      |
| <b>The child reminds me about the exercises</b>          | —      |
| <b>The child is interested in their progress</b>         | —      |
| <b>The child is proud of their achievements</b>          | —      |

Average score: \_\_\_\_ / 10

Source: Dehtiarenko and Pavlova (2019)

**Appendix B****Examples of corrective exercises****Table B.1.** Traditional exercises (control group)

| No | Exercise name                                 | Purpose                       | Equipment             | Duration |
|----|-----------------------------------------------|-------------------------------|-----------------------|----------|
| 1  | “Smile”                                       | Development of lip muscles    | Mirror                | 2        |
| 2  | “Clock”                                       | Tongue mobility               | Mirror                | 3        |
| 3  | Positioning [S] with a probe                  | Formation of articulation [S] | Probe-spatula, mirror | 10       |
| 4  | Automation of [C] in syllables                | Consolidation of sound        | Cards with syllables  | 7        |
| 5  | “Clap your hands when you hear the sound [C]” | Phonemic hearing              | —                     | 5        |
| 6  | “Magic bag”                                   | Vocabulary enrichment         | Pouch, toys           | 5        |
| 7  | “One-many”                                    | Grammar (plural)              | Subject cards         | 5 min    |

Source: Ribtsun (2012), Tarasun (2017), Trofymenko (2014)

**Table B.2.** Exercises with digital tools (experimental group)

| No | Exercise name      | Digital tool         | Advantages of the digital tool                                                         | Duration |
|----|--------------------|----------------------|----------------------------------------------------------------------------------------|----------|
| 1  | “Smile” + 3D model | Articulation Station | Visualization of the position of the tongue and lips; ability to rotate the model 360° | 3        |

|   |                         |                      |                                                                                             |          |
|---|-------------------------|----------------------|---------------------------------------------------------------------------------------------|----------|
| 2 | Automation [R] + game   | “Pop the bubbles”    | Immediate feedback; gamification; scoring system; progress chart                            | 10       |
| 3 | Staging [C] + analysis  | Speech Blubs         | Face recognition; sound wave analysis; green/red screen                                     | 10       |
| 4 | Phonemic hearing + game | “Phonemic Detective” | Interactive game; dynamic pace; automatic calculation of results                            | 7        |
| 5 | Vocabulary + flashcards | Digital Flashcards   | Voice recording by a native speaker; multisensory learning; auto-checking                   | 5        |
| 6 | AAC communication       | Grid 3 / Proloquo2Go | Speech synthesis; pictograms; “voice” for nonverbal children                                | Constant |
| 7 | Breathing exercise      | Breathing App        | Microphone reacts to the force of exhalation; visualization; “Blow Away the Butterfly” game | 3 min    |

Source: Attwell et al. (2022), Saeedi et al. (2022), Kadis et al. (2014)

## Appendix C

### Statistical calculations

**Table C.1.** Primary sound production data\*

| No                   | Age | Gender | Diagnosis                          | Before | After | Increase |
|----------------------|-----|--------|------------------------------------|--------|-------|----------|
| Control group (n=22) |     |        |                                    |        |       |          |
| K01                  | 5.2 | M      | Phonetic-phonemic underdevelopment | 14     | 18    | +4       |
| K02                  | 6.1 | F      | Dysarthria                         | 10     | 13    | +3       |
| K03                  | 5.8 | M      | Phonetic-phonemic underdevelopment | 13     | 17    | +4       |
| K04                  | 6.5 | M      | Speech Development Delay           | 11     | 15    | +4       |
| K05                  | 5.9 | F      | Phonetic-phonemic underdevelopment | 14     | 19    | +5       |
| K06                  | 6.3 | M      | Dysarthria                         | 9      | 12    | +3       |
| K07                  | 5.6 | F      | Phonetic-phonemic underdevelopment | 15     | 19    | +4       |
| K08                  | 6.7 | M      | Speech Development Delay           | 10     | 14    | +4       |
| K09                  | 5.4 | F      | Phonetic-phonemic underdevelopment | 13     | 17    | +4       |
| K10                  | 6.0 | M      | Dysarthria                         | 11     | 15    | +4       |
| K11                  | 6.4 | F      | Speech Development Delay           | 12     | 16    | +4       |
| K12                  | 5.7 | M      | Phonetic-phonemic underdevelopment | 14     | 18    | +4       |
| K13                  | 6.2 | F      | Dysarthria                         | 10     | 13    | +3       |

|                           |            |               |                                    |              |              |                 |
|---------------------------|------------|---------------|------------------------------------|--------------|--------------|-----------------|
| <b>K14</b>                | 5.5        | M             | Phonetic-phonemic underdevelopment | 13           | 18           | +5              |
| <b>K15</b>                | 6.6        | F             | Speech Development Delay           | 11           | 15           | +4              |
| <b>K16</b>                | 5.9        | M             | Dysarthria                         | 12           | 16           | +4              |
| <b>K17</b>                | 6.1        | F             | Phonetic-phonemic underdevelopment | 14           | 19           | +5              |
| <b>K18</b>                | 5.8        | M             | Speech Development Delay           | 10           | 14           | +4              |
| <b>K19</b>                | 6.3        | F             | Dysarthria                         | 11           | 15           | +4              |
| <b>K20</b>                | 5.6        | M             | Phonetic-phonemic underdevelopment | 13           | 17           | +4              |
| <b>K21</b>                | 6.4        | F             | Speech Development Delay           | 12           | 17           | +5              |
| <b>K22</b>                | 6          | M             | Dysarthria                         | 10           | 14           | +4              |
| <b>M±SD</b>               | 6.1±0.8    | –             | –                                  | 12.3±2.1     | 16.4±2.0     | +4.1            |
| Experimental group (n=23) |            |               |                                    |              |              |                 |
| <b>No</b>                 | <b>Age</b> | <b>Gender</b> | <b>Diagnosis</b>                   | <b>Up to</b> | <b>After</b> | <b>Increase</b> |
| <b>E01</b>                | 5.5        | M             | Phonetic-phonemic underdevelopment | 13           | 21           | +8              |
| <b>E02</b>                | 6.3        | F             | Dysarthria                         | 11           | 18           | +7              |
| <b>E03</b>                | 5.9        | M             | Phonetic-phonemic underdevelopment | 14           | 22           | +8              |
| <b>E04</b>                | 6.1        | F             | Speech Development Delay           | 10           | 17           | +7              |
| <b>E05</b>                | 6.2        | M             | Phonetic-phonemic underdevelopment | 13           | 22           | +9              |
| <b>E06</b>                | 5.7        | F             | Nonverbal (AAC)                    | 0            | 0            | AAC: 45%        |
| <b>E07</b>                | 6.4        | M             | Nonverbal (AAC)                    | 0            | 0            | AAC: 42%        |
| <b>E08</b>                | 5.8        | F             | Nonverbal (AAC)                    | 0            | 0            | AAC: 42%        |
| <b>E09</b>                | 6          | M             | Dysarthria                         | 12           | 20           | +8              |
| <b>E10</b>                | 5.6        | F             | Phonetic-phonemic underdevelopment | 14           | 23           | +9              |
| <b>E11</b>                | 6.5        | M             | Speech Development Delay           | 11           | 18           | +7              |
| <b>E12</b>                | 5.9        | F             | Phonetic-phonemic underdevelopment | 13           | 21           | +8              |
| <b>E13</b>                | 6.3        | M             | Dysarthria                         | 10           | 17           | +7              |
| <b>E14</b>                | 5.4        | F             | Phonetic-phonemic underdevelopment | 15           | 23           | +8              |
| <b>E15</b>                | 6.6        | M             | Speech Development Delay           | 9            | 16           | +7              |
| <b>E16</b>                | 5.8        | F             | Dysarthria                         | 12           | 19           | +7              |
| <b>E17</b>                | 6.1        | M             | Phonetic-phonemic underdevelopment | 14           | 22           | +8              |
| <b>E18</b>                | 5.7        | F             | Speech Development Delay           | 11           | 19           | +8              |

|             |                |   |                                    |                 |                 |             |
|-------------|----------------|---|------------------------------------|-----------------|-----------------|-------------|
| <b>E19</b>  | 6.4            | M | Dysarthria                         | 10              | 18              | +8          |
| <b>E20</b>  | 5.5            | F | Phonetic-phonemic underdevelopment | 13              | 21              | +8          |
| <b>E21</b>  | 6.2            | M | Speech Development Delay           | 12              | 20              | +8          |
| <b>E22</b>  | 5.9            | F | Dysarthria                         | 11              | 19              | +8          |
| <b>E23</b>  | 6.0            | M | Phonetic-phonemic underdevelopment | 14              | 21              | +7          |
| <b>M±SD</b> | <b>6.0±0.7</b> | — | —                                  | <b>12.5±2.0</b> | <b>19.8±1.8</b> | <b>+7.3</b> |

\*Source: calculated by the author

Note: \*For nonverbal children (E06-E08), the indicator “AAC: 42-45%” means the percentage of successful communicative acts through an AAC communicator. Their speech remained at 0 verbal sounds, but communication became possible through alternative means

### C.2. Calculation of the t-criterion (speech after intervention)

$$t = (M_1 - M_2) / \sqrt{(SD_1^2/n_1 + SD_2^2/n_2)}$$

$$t = (19.8 - 16.4) / \sqrt{(1.8^2/23 + 2.0^2/22)}$$

$$t = 3.4 / \sqrt{(0.141 + 0.182)}$$

$$t = 3.4 / 0.568 = 5.82$$

$p < 0.001$  (highly significant difference)

### C.3. Calculation of Cohen's d (effect size)

$$SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2) / 2)}$$

$$SD_{pooled} = \sqrt{((1.8^2 + 2.0^2) / 2)} = \sqrt{(3.24 + 4.00) / 2} = 1.90$$

$$d = (M_1 - M_2) / SD_{pooled}$$

$$d = (19.8 - 16.4) / 1.90 = 1.89$$

Interpretation:  $d = 1.89$  — large effect

( $d > 0.8$  is considered a large effect according to Cohen)

**Table C.4.** Summary table of all indicators

| Parameter            | Control Before | Control After | Exp. Before | Exp. After | t-value | p      | Cohen's d |
|----------------------|----------------|---------------|-------------|------------|---------|--------|-----------|
| Sound pronunciation  | 12.3±2.1       | 16.4±2.0      | 12.5±2.0    | 19.8±1.8   | 5.82    | <0.001 | 1.89      |
| Phonemic hearing (%) | 45.2±8.3       | 62.1±7.5      | 44.1±7.9    | 78.3±6.2   | 7.82    | <0.001 | 2.24      |

|                                 |          |          |          |          |      |        |      |
|---------------------------------|----------|----------|----------|----------|------|--------|------|
| <b>Vocabulary (words)</b>       | 950±175  | 1180±165 | 940±180  | 1410±195 | 4.28 | <0.001 | 1.26 |
| <b>Grammar (%)</b>              | 58.1±8.8 | 71.3±8.0 | 57.2±9.1 | 82.5±7.3 | 5.12 | <0.001 | 1.51 |
| <b>Motivation (1-10)</b>        | 3.2±0.8  | 3.6±0.9  | 3.1±0.9  | 5.8±0.7  | 9.1  | <0.001 | 3.12 |
| <b>Communication activities</b> | 4.1±1.7  | 6.8±1.9  | 4.3±1.8  | 11.7±2.1 | 8.34 | <0.001 | 2.45 |

Source: calculated by the author