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ORIGINAL PAPER

Exploring the Opportunities for Online Assessment of Phonological Awareness at the Beginning of Schooling

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Abstract

Phonological awareness plays a key role in learning to read; therefore, its assessment has received a lot of attention. Research in the domain of phonological awareness has been characterized by attempts to develop reliable and valid assessment tools for diverse populations. Over the past few decades, phonological awareness assessment has gone through a significant evolution. Computer-delivered tests have led to new opportunities. Integrating the new medium into the testing process offers multiple benefits compared to traditional face-to-face and paper-and-pencil methods. Studies on the feasibility, structure and results of online assessments are scarce. The aim of the present study is to explore the possibilities for a technology-based assessment of phonological awareness of Hungarian first language learners ($N = 5838$) and to develop a reliable and valid online instrument. Results suggest that we have managed to develop a valid, reliable and easy-to-use online phonological awareness test that can be used easily in elementary school classroom settings. The unique results about the multi-dimensional nature of the construct can help rethinking and reconceptualizing phonological assessment in a wide range of languages. Since Hungarian is a language with a high level of orthographic transparency, the results could be generalized to other languages with similar qualities.

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Keywords Phonological awareness · Multiple dimensions of the construct · Online assessment · School-readiness

Résumé
La conscience phonologique joue un rôle clé dans l'apprentissage de la lecture ; par conséquent, son évaluation a reçu beaucoup d'attention. La recherche dans le domaine de la conscience phonologique a été caractérisée par des tentatives de développer des outils d'évaluation fiables et valides pour diverses populations. Au cours des dernières décennies, l'évaluation de la conscience phonologique a connu une évolution significative. Les tests informatisés ont ouvert de nouvelles opportunités. L'intégration du nouveau support dans le processus de test offre de multiples avantages par rapport aux méthodes traditionnelles en face à face et papier-crayon. Les études sur la faisabilité, la structure et les résultats des évaluations en ligne sont rares. Le but de la présente étude est d'explorer les possibilités d'une évaluation de la conscience phonologique des apprenants de langue maternelle hongroise (N = 5838) basée sur la technologie et de développer un instrument d'évaluation en ligne sûr et valide.
Les résultats suggèrent que nous avons réussi à développer un test de conscience phonologique en ligne valide, fiable et facile à utiliser qui peut être employé facilement dans les salles de classe du primaire.
Les résultats uniques sur la nature multidimensionnelle de la construction peuvent aider à repenser et à reconceptualiser l'évaluation phonologique dans un large éventail de langues. Le hongrois étant une langue avec un niveau élevé de transparence orthographique, les résultats pourraient être généralisés à d'autres langues ayant des qualités similaires.

Resumen
La conciencia fonológica juega un papel clave en el aprendizaje de la lectura; por lo tanto,su evaluación ha recibido mucha atención. La investigación sobre el dominio de la conciencia fonológica se ha caracterizado por sus intentos de desarrollar herramientas de evaluación confiables y válidas para diversas poblaciones. En las últimas décadas, la evaluación de la conciencia fonológica ha experimentado una evolución significativa. Exámenes hechos a ordenador han generado nuevas oportunidades. La integración del nuevo medio en el proceso de prueba ofrece múltiples beneficios en comparación con los métodos tradicionales como exámenes orales o escritos. Los estudios sobre la viabilidad, la estructura y los resultados de las evaluacionesonline son escasos. El objetivo del presente estudio es explorar las posibilidades de una evaluación basada en la tecnología de la conciencia fonológica de los estudiantes de lengua materna húngara (N = 5838) y desarrollar un instrumento online confiable y válido. Los resultados sugieren que hemos logrado desarrollar una prueba de conciencia fonológica en línea válida, confiable y fácil de usar que se puede utilizar fácilmente en las aulas de los colegios. Los resultados únicos sobre la naturaleza multidimensional del constructo pueden ayudar a repensar y reconceptualizar la evaluación fonológica en una amplia gama de idiomas. Dado que el húngaro es un idioma conun alto nivel de transparencia ortográfica, los resultados podrían generalizarse a otros idiomas con cualidades similares.

Introduction

As a key predictor of reading achievement (Lerner & Lonigan, 2016; Zugarramurdi et al., 2022) across languages, phonological awareness has been widely researched over the past decades. The assessment of the domain has been enriched with refined methodologies applying over 20 task types relying on face-to-face interaction between the examiner and the examinee (Farrall, 2012). Technological advancements have gradually transformed the whole continuum of educational assessments in this domain as well (Csapó & Molnár, 2019). As a result, computer-delivered tests including e.g., Comprehensive Test of Phonological Processing (CTOPP) (Wagner et al., 1999) and Dyslexia Differential Diagnosis Maastricht-Hungarian Test (3DM-H) (Tóth et al., 2014) offer new opportunities in phonological awareness assessment.

Integrating the new medium of delivery into the testing process offers multiple benefits. Besides time and cost efficiency, it allows researchers to implement large-scale assessments using standardized administration conditions characterized by a good quality sound system, standard voice, articulation, rate of delivery and timing (Molnár & Csapó, 2019). These factors may have a significant effect on different components of phonological awareness. For example, sound quality, voice and articulation can influence speech perception, whereas the rate of delivery and timing can affect phonological memory. Additionally, an online instrument using a child friendly design can reduce distractibility and anxiety and increase intrinsic motivation and engagement facilitating test-takers' performance.

In line with these considerations, we explored how online testing of this domain can be used with Hungarian children between the ages of 4 and 8. Some traditional face-to-face tests of phonological awareness are available for individual testing of Hungarian native speakers. These are adapted versions of English tests (Jordanidisz, 2009; Lőrik, 2006; Lőrik & Májercsik, 2015). We drew on these Hungarian tests, studied international assessment practices and papers on developmental theories in the domain and developed a comprehensive test of phonological awareness covering multiple levels and dimensions that we transferred to an online platform.

We developed a range of tasks with different visual representations and response formats measuring the phonological awareness construct and tested them on an online platform. As a result, an online assessment instrument providing a wide coverage of the construct became available. We administered the test to over 5000 Hungarian first graders (age: 6–7) and validated it in order to pave the way for a successful reading developmental trajectory.

The aim of the present study is to offer insights into how this technology-based assessment tool of phonological awareness that could be used in elementary school classroom settings was validated and how it worked.

First, we outline of the definitions and development of phonological awareness, then, we discuss assessment practices before sharing information on the instrument and its psychometric properties. Finally, we point to the findings that lend support to and acknowledge the strengths of assessing phonological awareness on an online platform.

Phonological Awareness: Definition and Development

Recently, phonological awareness has been the focus of research as a key element in early literacy development and as an important and reliable predictor of later reading ability (e.g., Nakamura, 2018; Ouellette & Haley, 2013; Shanahan, 2012). Phonological awareness is an umbrella term (Goswami & Bryant, 1990) used to refer to sensitivity to the sound structure of oral language and the ability to identify, discriminate and manipulate units of oral language (Ehri et al., 2001; Hand et al., 2022; Sénéchal et al., 2004). The development of phonological awareness forms a continuum. It develops from the ability to distinguish and manipulate larger linguistic units (e.g., syllables) to smaller phonological segment awareness (Carroll et al., 2003; Ziegler & Goswami, 2005). Sensitivity to the smaller segments of individual speech sounds is referred to as phonemic awareness, distinguishing it from the umbrella term, phonological awareness (Ouellette & Haley, 2013). Phonemic awareness comprises "rudimentary phonological skills", such as recognizing that two words rhyme and have a sound in common (Anthony & Francis, 2005; Goswami & Bryant, 1990; Ross & Joseph, 2019).

The developmental process can be conceptualized in terms of linguistic segment size, cognitive complexity, and level of conscious awareness. As far as cognitive complexity is concerned, phonological awareness develops from implicit sensitivity to explicit awareness. Implicit awareness is related to word and syllable sound patterns, whereas explicit awareness is associated with phoneme manipulation (Stanovich, 1992). The ability to handle linguistic units with increasing complexity emerges gradually. Research shows that syllable awareness develops in the preschool period or well before it (Goswami & Bryant, 1990; Suortti & Lipponen, 2016; Wasserstein & Lipka, 2019). Although children achieve minimal levels of phoneme awareness prior to literacy instruction, sensitivity to phonemes evolves quickly once literacy instruction begins (Anthony & Francis, 2005; Blomert & Csépe, 2012). In addition, the implicit-explicit dimension seems to be intertwined with findings that identify two stages of development. As a first stage, sensitivity to the more global aspects of the phonological structure of words, that is, access to syllables, onset and rime, emerges as a result of spontaneous development, whereas the second stage, comprising the ability to identify, break down and manipulate speech sounds, develops as a result of learning to read (Tóth & Csépe, 2008). The development of phonemic awareness and reading ability is reciprocal (Lerkkanen et al., 2004).

These stages are typical across all languages; however, there are differences between how phonological awareness develops in English and Hungarian. According to a study comparing the phonological awareness of Hungarian monolingual children learning to read in Hungarian and Hungarian-English bilingual children learning to read in English when their dominant language is Hungarian, the differences emanate from the specific phonological structure of the language, the time learning to read starts, and the methods used for teaching reading (Jordanidisz, 2011).

Phonological awareness in Hungarian is influenced by (high, medium and low) word frequency and semantic interpretability (word and nonword) in which the stimulus speech sound is, the position of the stimulus speech sound (at the beginning, in

the middle, at the end), speech sound quality (voiced/voiceless consonant, duration, phonation position, phonation mode) and speech sound environment (before vowel, before consonant, after vowel, after consonant, between two vowels, between two consonants) (Kassai, 2006).

Assessment of Phonological Awareness

The recognition that achieving reading proficiency is essential for individual development and successful life led to increased testing of reading thus making the domain the most frequently assessed entity after temperature (Stenner, 1996). If one looks at the number of instruments available for determining the developmental level of phonological awareness as a primary prereading skill in English, phonological awareness ranks third and it closely follows reading in the league table. The reason for this is that abundant research provided empirical support that targeted development of phonological awareness has a tangible impact on reading outcomes regardless of the orthography of the language (Goswami, 1999).

The majority of instruments were designed for speakers of English. Most tests were developed for face-to-face administration, but research-based computer-assisted tests are also gaining ground. Carson's (2017) computer-based phonological awareness screening and monitoring tool was developed for 5-year-olds. The computerized tools in Dutch (3DM Dyslexia Differential Diagnosis Test; Blomert & Vaessen, 2009) and Hungarian (3DM-H; Tóth et al., 2014) enabling a differential diagnosis of dyslexia target a narrow segment of the phonological awareness construct. They use a single specific task type, phoneme deletion, to assess phonemic awareness. CTOPP, a more comprehensive test of phonological processing in the English language, comprises tasks for the assessment of six components of phonological awareness (Wagner et al., 1999); it uses recorded audio files providing not only a sound system of good quality but also assuring standard administration of the test.

The instruments integrating technology and assessment have benefits generalizable across all domains. First, they make test administration less time consuming and resource intensive. Second, test-takers may perceive it as a more motivating environment to solve tasks in. Third, immediate feedback inherent in most computer-based tests can help timely intervention. Additionally, computer-delivered tests can provide remedies to some domain-specific testing problems arising from the lack of standardization such as validity of different response formats, validity of different task types, and aspects of vocal delivery of items (Farrall, 2012). During a live word test recording, the test administrator sits in front of the child in a quiet room. They see each other, and they can read one another's facial expressions, gestures and postures. The test administrator can influence the outcome of the test by implying the correct answer with their pitch or nonverbal cues; even their common cold or hoarseness can affect their speech sound production and thus the child's test performance and test validity. The test administrator must focus not only on the monotony of their own voice and be aware of their gestures, but also on accurate scoring. The test delivered online changes the responsibilities of the test administrator. The items

are not read aloud, thus, by means of the recorded audio material, all children hear the same sounds in the same conditions (Cassady et al., 2005).

It is a general requirement that phonological awareness tests should be subject to general testing standards. Studies attempted to find empirical evidence for the construct validity of phonological awareness tests; thus, research in the domain resulted in a few theoretical models. Adams (1990) claimed that phonological awareness comprises five levels, Goswami and Bryant (1990) distinguished three levels, whereas Barbour et al. (2003) proposed a two-dimensional model. According to Adams (1990), the theoretical levels refer to the cognitive skills involved in the manipulation of the linguistic units. However, in the latter two models the size of the linguistic units is dominant.

Several studies explored the underlying measurement model of phonological awareness. The results of these studies show an even more diverse picture of the construct than the theoretical models mentioned above. Wagner and Torgesen (1987) found that one factor best explained the performance of 143 children on nine different measures of phonological sensitivity. Similarly, Schatschneider et al. (1999), Branum-Martin et al. (2006) and Khalaf et al. (2019) found phonological awareness to be a one-factorial entity, whereas Yopp's results (1988) supported a two-factor model. Findings of other studies examining the construct of phonological awareness showed a more diverse picture. Hoien et al. (1995) found separate factors for phoneme sensitivity, syllable sensitivity, and rhyme sensitivity in children between 6 and 8. Stanovich et al.'s data (1984) lend support to a 10-dimensional, whereas Stahl and Murray's (1994) findings show a model fit of a 14-dimensional model.

These studies differ in the languages in which they were conducted. They also worked with different sample sizes, different age groups and they used different measures of phonological awareness with versatile dimensions and task types. Most importantly, the vast majority used data collected face-to-face, which challenged the objectivity and validity of assessments. Furthermore, they differ in the statistical method they used to identify the underlying dimensionality of the construct. In sum, there are many ways to assess phonological awareness. Lack of standardization from one test to another may leave educators confused regarding the number of key components and potential differences in scores.

The Context of the Present Study

Research on skills predicting later academic success has a long tradition in Hungary. Our study is in line with previous research in three respects: (1) It is embedded in large-scale assessments into all learners' development in school-readiness, (2) it is part of a shift from traditional assessments to computer-based ones, and (3) a line of previous research, a predecessor of the present work, validated a school readiness test-battery called PREFER (Hungarian acronym for Preventive Assessment System of Development) in the early 1980s (Nagy, 1980). The battery was further developed into a standardized, research-based version called DIFER (Hungarian acronym for Diagnostic Assessment System of Development; Nagy et al., 2004). Although the administration of the test is not compulsory, it is considered the official indicator of

school readiness by specialists of early childhood development. School teachers are obliged by the act on national public education to administer the test to struggling students upon entering elementary education at age 6. Test administration requires training.

DIFER is suitable for the face-to-face individual assessment of domains identified as good predictors of later educational success (Csapó, 2013). DIFER has also been used in schools for monitoring children's basic social skills, basic numeracy skills, fine motor skills for writing, knowledge of relational words, inductive reasoning, and a segment of phonological awareness, speech sound discrimination, between the ages of 4–8. The last subtest of DIFER measures phonological awareness, speech sound perception and recognition with 60 items reflecting the importance of this skill. All items focus on speech sound discrimination, with factors influencing item difficulty such as length of sound, the phonetic environment, manner of articulation, place of articulation, and phonation.

Although the subtest taps into the domain of phonological awareness, it fails to give a comprehensive picture of what students know and can and cannot do in phonological awareness. The DIFER test battery was designed along the principles of a dated developmental theory of phonological awareness: for example, it does not measure syllable awareness as a major component of phonological awareness, and the range of productive tasks prompting students to say something (National Research Council—NRC, 2001, p. 44) is limited. To date there is no research-based instrument for the comprehensive assessment of phonological awareness in Hungarian.

In recent years, educational assessment, including large-scale international assessment programs and classroom diagnostic assessment, has migrated to computers and several other means of information-communication technology (Csapó et al., 2012). Technology-based tests are less expensive and easier to administer alternatives to traditional paper-and-pencil tests and they offer new features and better psychometric parameters (Clariana & Wallace, 2002; Kingston, 2009; Wang et al., 2008). They open up new opportunities for developing tests for transition from kindergarten to school (Carson et al., 2011). Partial computerization of the DIFER was successfully piloted with promising results. The speech sound differentiation subtest was not included in the computer version. Data showed that if some subtests of the DIFER face-to-face school-readiness battery were computerized, the objectivity and reliability of the tests improved significantly (Csapó et al., 2014).

Objectives

The aim of the present study is to examine the possibilities of developing a new comprehensive online test of phonological awareness for students who start elementary school. As phonological awareness is a prerequisite for reading, an easy-to-use instrument could provide teachers with the necessary information to explore the bottlenecks in students' development and could serve as a starting point for tailor-made, personalized development in the first school year, if necessary.

The norm referenced test was designed to help teachers determine students' strengths and weaknesses in phonological processing development/phonological awareness. In this study we explore some attributes and the usability of the new Phonological Awareness Test (PHAT). More specifically, we aim to examine the psychometric properties of the online phonological awareness test and students' phonological awareness achievement at the beginning of formal schooling.

Method

Sample

The study was implemented as a part of the Hungarian Educational Longitudinal Program (HELP, see Csapó, 2014) that aims to monitor students' development from the beginning of schooling (age 6) to the end of compulsory education (age 16). HELP started in 2003 and new cohorts have been included every four years. The samples for the program are representatively selected from all elementary schools in Hungary.

The examined cohort entered the program involving 292 classes at 178 schools. This is the first cohort assessed with online instruments. The online phonological awareness test was administered to 5,838 Hungarian first graders ($M_{age} = 7.10$, $SD_{age} = 4.88$, the age range is between 5.08 and 9.17, boys: 50.8%, girls: 49.2%) one month after entering school. The sample constituted 6.05% of the population.

According to the regulations in effect at the time of the assessment, all children had to be enrolled in kindergarten education at the age of 5. Therefore, all students in the sample had attended kindergarten for at least one year nurturing children's most crucial foundational skills for successful school start. The national curriculum for kindergarten education defines the areas that need to be developed and nurtured during kindergarten years and it includes activities that could contribute to their development in a playful manner. First language literacy education is to be integrated in all activities and it is developed through children's stories, poems and language play. Phonological awareness as a skill is not included in the national program. Kindergarten teachers do not initiate literacy activities explicitly related to knowledge about print; phonological awareness, writing or reading are not targeted.

The sample comprised students characterized by typical language development in Hungarian as their first language. Each student involved in the study attended a public school, as the examination of private schools is beyond the scope of the Hungarian Educational Longitudinal Program.

Instruments

Information-Communication Technology (ICT) Familiarity Training

A brief familiarity training was administered to all children in ICT to check if they had the basic skills to do the computerized test items. The test consisted of 5

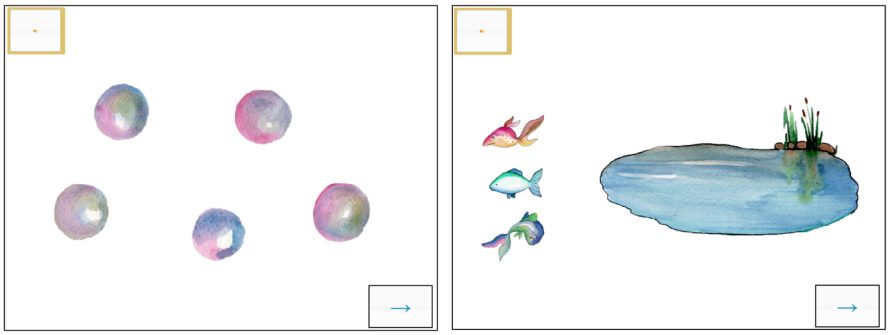

Fig. 1 Sample Items from the ICT Familiarity Training**.** Instructions to the left side: Pop all the bubbles. Click on them! Instructions to the right side: Drag and put all the fish into the lake!

Table 1 Structure of the phonological awareness test

Dimension	Subtest	Number of items	
Syllable awareness	Syllable synthesis	5	13
	Syllable segmentation	5	
	Syllable deletion	3	
Phonemic awareness	Phoneme identification in different sound environments with words and nonwords	8 (4–4)	38
	Identification of the position of phoneme with words and nonwords	10 (5–5)	
	Identification of initial phonemes	5	
	Phoneme synthesis	5	
	Phoneme segmentation	5	
	Phoneme deletion	5	
Total test			51

clicking tasks and 5 tasks moving objects on the screen by drag and drop (Fig. 1). Students practiced functions until they achieved 100% proficiency before moving on to the phonological awareness test.

Phonological Awareness Assessment Instrument

The test is innovative in the field of phonological awareness assessment in several ways: (1) It offers a diverse selection of tasks, (2) multimedia tools are applied for presenting test stimuli, (3) it enables different response formats, (4) all instructions for the items were given in voices recorded by trained professional speakers, (5) and the rate of stimuli delivery was the same across the tasks.

The phonological awareness test contains 51 closed items and 9 subtests (Table 1). The test taps into children's knowledge about the dimensionality of phonological awareness proposed in previous studies and discussed in the

Fig. 2 Sample item from the syllable synthesis subtest (Instruction: I will say a word. Listen carefully, I will say it slowly, sound by sound. Click on the picture that shows the word you hear!)

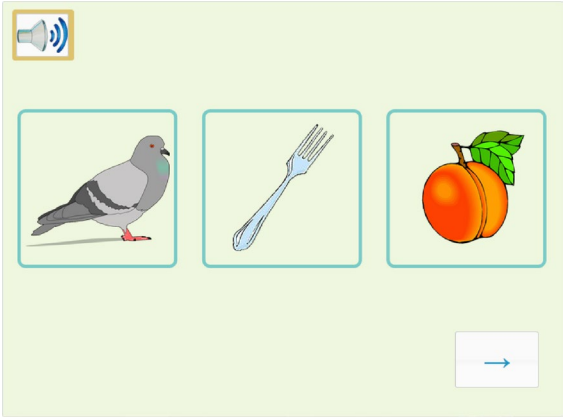

Fig. 3 Sample item from the syllable deletion subtest (Instruction: You will hear a word. Omit the last syllable. Click on the picture that shows the new word!)

overview of the literature (Adams, 1990; Barbour et al., 2003; Goswami & Bryant, 1990). It covers two levels (the syllable and the phonemic level) of the construct representing different segment sizes of oral language. It also integrates different tasks for the assessment of cognitive activities. The tasks require children to synthesize, segment and delete linguistic units of certain sizes (see Figs. 2, 3, 4, 5, 6). The phonemic level comprises items measuring the extent to which students can identify phonemes (i.e., phoneme identification, identification of the position of phoneme, identification of initial phonemes). The items were piloted in 2014 and they worked as expected (Török et al., 2016).

The tasks comprise words and nonwords. The vocabulary of the test was drawn from a Hungarian corpus Szószablya, the largest tokenized text collection in the Hungarian language (Oravecz et al., 2014). Only lemmas were used. The database helped the research design with data on word frequency, syllable count and CV skeleton. The nonwords were taken from a valid Hungarian nonword test

Fig. 4 Sample item from the identification of the position of phoneme subtest (Instruction: Where can you hear the sound in the word? At the beginning, in the middle or at the end? Click on the corresponding part of the train!)

Fig. 5 Sample item from the phoneme deletion subtest (Instruction: You will hear a word. Omit the word without the last sound! Click on the picture that shows the new word!)

Fig. 6 Sample item from the syllable segmentation subtest (Instruction: You will hear a word. How many times do you clap for the word? Move the robot to the corresponding square!)

(Racsmány et al., 2005). The language specific nonwords were used for studies in psycholinguistics (e.g., Lukács et al., 2008).

To present items of versatile levels of difficulty the test comprises high, medium and low frequency words with different numbers of syllables (1–7) and phonemes (2–11). In the phoneme awareness tasks, the manner and the place of articulation of the sound and position of sound within the word are also relevant aspects (see Kiss et al., 2015).

The test comprises two subtests requiring students to use the drag and drop and seven to use the click function. To complete the test children first had to click onto the loudspeaker icon on the screen so that they could listen to the instruction and the sound stimuli. In all cases they could listen to the items only once.

The professional speaker who recorded the stimuli was a middle-aged male native speaker of Hungarian with excellent speech sound qualities (no speech defects). He obtained a teaching degree and has worked as a television anchor for two decades. The speaker was given exhaustive information about phonological awareness, about the items and the objectives of the test and the student population. He was also trained about speech sounds by the test developers. He has vast experience in item development projects such as ours. The recordings were all made in the same place soundproof room and technical conditions. According to the values of the signal/noise ratio of the audio materials recorded in the room, this soundproof room is suitable for making high-quality audio recordings. The recording is digital. A wav file with a bit density of 2304 kb/s is created, during the post-processing, 1536 kb/s Wav files are created. The sound level is set between − 12 and − 6 dB during post-production.

The test was standardized and the subtests were presented to all students in the same order. From the point of view of student-level feedback and class-level usability, we considered it important that the order of the subtests is the same.

Procedure

Students completed the tests at the beginning of the school year, in October, by means of the eDia online assessment platform (Csapó & Molnár, 2019) at their school using locally available personal computers. They had 45 min (one class) to complete the test. After beginning the session, all instructions were delivered online. Headphones ensured test-taking at an individual pace. The children's classroom teachers supervised the testing procedure. After completing the tests, students received immediate visual feedback about their results, as scoring of the computer-based assessment tool was automatic. The correct answer was worth 1 point and 0 point was given for the wrong answer. Teachers received detailed statistical descriptions of their students' achievements.

Data were collected and stored anonymously. The research was approved by the Institutional Review Board. Parents were informed about the purposes, processes, methods, data governance and use, and their right to withdraw their child before data collection. All participants' parents signed an informed consent form about their child's participation in the study.

Method of Data Analyses

In this study, we investigated the measurement models underlying the phonological awareness test. It was examined along (1) the size of linguistic units (syllables and phonemes), (2) the cognitive operations (analysis, synthesis, segmentation, and deletion) used during task solving, and (3) the operations performed with the linguistic unit (see Table 1). Confirmatory factor analyses (CFA) were used to test the underlying measurement models for phonological awareness. All measurement models were computed with MPlus 7.3 (Muthén & Muthén, 2010). Weighted Least Squares and Mean- and Variance-adjusted (WLSMV) estimation was used. Different fit indices, such as the Tucker–Lewis Index (TLI), the comparative fit index (CFI) and the root mean square error of approximation (RMSEA) were computed to assist in determining model fit. Nested model comparisons were conducted using a special $\chi 2$ difference test for the WLSMV estimator. Data were also analyzed with descriptive statistical methods and paired-samples *t*-test.

Analysis of the Results

The Psychometric Properties of the Test

The online phonological awareness test proved to be reliable (Cronbach's $\alpha = 0.90$) both at syllable (Cronbach's $\alpha = 0.79$) and phonemic level (Cronbach's $\alpha = 0.89$), the internal consistency of the test was good. CFA were conducted to test the underlying measurement model for phonological awareness. Since construct validity analyses in this domain are inconclusive, we tested different models with different dimensions reflecting our assumptions based on theoretical foundations and previous empirical findings. We also relied on our literature review of what factors influence phonological awareness when establishing theoretical models. Accordingly, 1-, 2-, 4-, 7-, 9- and 11-dimensional models were tested.

(1) The 1-dimensional model combines all the items under one general factor: phonological awareness.
(2) The 2-dimensional model suggests that the size of linguistic units (syllables and phonemes) are the main organizational principles of the domain of phonological awareness.
(3) The 4-dimensional model corresponds to the four different cognitive activities applied (analysis, synthesis, segmentation, and deletion) during the operation of this skill.
(4) The 7-dimensional model reflects the hypothesis that each subtest falls into a different dimension.
(5) The 9-dimensional model puts all items within phoneme identification into different factors (identification of initial phonemes, identification the position of

the phonemes within the word and phoneme identification in different sound environments).

(6) In addition to being sensitive to phoneme identification, the 11-dimensional model is based on the hypothesis that items would also be grouped into different factors based on the word—nonword distinction.

The 7-, 9- and the 11-dimensional models showed an acceptable model fit (Table 2). We also tested which model fit the data better. χ^2-difference test showed that the 11-dimensional model fit the data significantly better than the 7- ($\chi^2 = 1277.73$; d$f = 15$; $p < 0.001$) or the 9-dimensional model ($\chi^2 = 148.32$; d$f = 19$; $p < 0.001$).

Students' Phonological Awareness Achievement

The means and standard deviations reveal that the instrument is suitable for the assessment of students on a wide phonological awareness spectrum. Results showed a significant difference ($t = 90.03$, $p < 0.000$) in students' achievement across the two main dimensions of the test. Their syllable awareness proved to be significantly better than their phoneme awareness. Data also suggested that students had the most difficulty in the segmentation tasks both in the syllable ($t = 81.03$, $p < 0.000$) and phoneme ($t = 139.88$, $p < 0.000$) dimensions. The synthesis and deletion of syllables and phonemes subtests were easier for the students. Their achievement was higher than 80% in these subtests (Table 3).

Testing Time and Dropout Rate

Students completed the test in 30.87 min on average (SD = 11.73); 73 students (1.25%) could not finish the test in a 45-min class. Therefore, the dropout rate was minimal, but further research should explore the reasons underlying these cases.

Table 2 Goodness of fit indices for testing the dimensionality of phonological awareness

Model	$\chi 2$	df	p	CFI	TLI	RMSEA (95% CI)
11-dimensional	8296.47	1169	.001	.936	.930	.032 (.031–.033)
9-dimensional	8385.36	1188	.001	.935	.931	.032 (.031–.033)
7-dimensional	11,199.79	1203	.001	.910	.905	.038 (.037–.038)
4-dimensional	23,876.02	1218	.001	.796	.787	.056 (.056–.057)
2-dimensional	23,359.87	1223	.001	.801	.793	.055 (.055–.056)
1-dimensional	33,969.65	1224	.001	.706	.694	.067 (.067–.068)

Table 3 Students' phonological awareness achievement

Dimension	Subtest	*M* (SD)	
Syllable awareness	Syllable synthesis	85.94 (23.26)	69.31 (29.54)
	Syllable segmentation	46.24 (36.26)	
	Syllable deletion	80.04 (26.80)	
Phoneme awareness	Phoneme identification in different sound environments with words and nonwords	58.82 (24.88)	45.05 (16.88)
	Identification of the position of phoneme with words and nonwords	51.53 (27.98)	
	Identification of initial phonemes	50.11 (34.78)	
	Phoneme synthesis	80.31 (25.83)	
	Phoneme segmentation	27.81 (30.64)	
	Phoneme deletion	81.11 (26.06)	
Total test			60.46 (18.45)

Discussion and Conclusion

The aim of this paper was to explore the possibilities for a technology-based assessment of phonological awareness. Results showed that the online assessment instrument for phonological awareness was reliable. As far as the underlying measurement model is concerned, several models were tested based on theoretical assumptions (Kassai, 2006) and previous findings of empirical studies (Hoien et al., 1995; Wagner & Torgesen, 1987; Yopp, 1988). Evidence for construct validity was provided for a 7-, 9- and 11-dimensional model; the 11-dimensional model proved to be the best representation of the construct. In the 11-dimensional model an additional aspect is the distinction between items containing words and nonwords. Our findings show that the assessment of phonological awareness needs a refined approach in terms of the size of the linguistic unit (syllable, phoneme), cognitive aspects (e.g., deletion, segmenting), word–non-word distinction and factors playing a key role in phoneme differentiation (e.g., manner and place of articulation). Taking a more differentiated approach toward item construction can help educators map students' achievement in a wider spectrum in this domain.

Findings showed that students achieved significantly higher scores in the syllable dimension than in the phoneme dimension. This outcome is in line with the literature claiming that syllable awareness develops first, and it is followed by phonemic awareness (Goswami & Bryant, 1990). Syllable awareness is developed in playful activities in kindergarten which could also be a possible reason for the higher test scores. Additionally, while syllable awareness is reinforced in the early years, the ability to identify and manipulate speech sounds becomes refined as children learn to read at school. Results on the cognitive activities students did in both dimensions revealed that the advantage students have in the syllable dimension is not uniform across all task types because segmentation proved to be significantly more difficult than the other tasks assessing syllable awareness. Interestingly, segmentation tasks proved to be similarly challenging also in the phoneme dimension. Data on testing time and dropout rate confirmed that a wide coverage of the domain could be achieved with the test and it is possible to administer it at full length during a 45-min class.

Automatic scoring, reduced time and cost of the testing process are all considered as advantages of technology-based assessment. The findings indicated that the PHAT was suitable for everyday school-practice and large-scale assessment of phonological awareness. The test can be applied in school practice to monitor and facilitate an individualized and personalized developmental process in the first school year.

In sum, the novelty of the PHAT lies in the fact that it integrates three important factors in phonological assessment. First, it is suitable for the in-depth exploration of students' skills as it is a comprehensive test for assessing phonological awareness covering multiple dimensions of the construct, second, it provides a valid and reliable technology-based alternative for face-to-face testing. Third, it can be easily used in a classroom setting providing an efficient and easy way of assessment for both students and teachers, immediate feedback can accelerate intervention.

Limitations

Our objective was to develop a comprehensive phonological awareness test that can help teachers' daily work in their classrooms. As our results show, the instrument had good psychometric properties, can be administered to first year children in less time than a class in one go. Although the study reached its objective, some limitations are also obvious.

The study was limited to assessing the construct of phonological awareness and developing an assessment instrument as comprehensive as possible, thus, data collection was limited to students' phonological awareness and other potentially confounding variables (such as SES) were not examined.

As we designed an instrument that is aligned with students' age idiosyncrasies in terms of the cognitive load induced by testing, we could not include more items into the dimensions of the test.

Finally, although validity may be examined from multiple aspects, this study only focused on internal structure validity and content validity. This limitation outlines a future direction for our research. Since phonological awareness is a key predictor of reading achievement, we intend to follow these students' development in their reading abilities and examine the predictive validity of the PHAT as well.

Authors' contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by AH and ET under the aegis of the MTA-SZTE Research Group on the Development of Competencies. All authors read and approved the final manuscript.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Informed consent The study took place with the informed consent of the participants.

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