ADPS—A Prescreening Tool for Students With Dyslexia in Learning Traditional Chinese

Ka-Yan Fung, Kit-Yi Tang, Tze Leung Rick Lui, Kuen-Fung Sin, Lik-Hang Lee, Huamin Qu, *Member, IEEE*, and Shenghui Song, *Senior Member, IEEE*

***Abstract*—Prescreening children for specific learning disabilities, e.g., dyslexia, is essential for effective intervention. With a quick and reliable prescreening result, special education coordinators (SENCOs) can provide students with early intervention and relieve their learning pressure. Unfortunately, due to the limited resources, many students in Hong Kong receive dyslexia assessments beyond the golden period, i.e., under the age of six. To this end, information technology could establish automatic prescreening tools to address this issue. However, dyslexia prescreening for children learning Chinese is challenging due to the lack of sound–script correlation in Chinese. In this article, an automatic dyslexia prescreening system (ADPS) is developed to provide a quick test to identify at-risk children. Through a two-stage approach, we first develop a gamified tool based on linguistic characteristics and then evaluate the result by a comparison study. Results from a pilot test on 30 students with dyslexia and 32 students without dyslexia indicate that the ADPS can effectively distinguish between two groups of students. Furthermore, the interactive design elements can motivate students to conduct the prescreening independently.**

***Index Terms*—Dyslexia, handwriting (HW), phonological awareness (PA), prescreening, Traditional Chinese, vocabulary knowledge (VK), working memory (WM).**

I. Introduction

DYSLEXIA is a prevalent neurodevelopmental disorder, which affects 5–10% of the global population and primarily impacts reading, writing, and spelling [1]. It poses unique challenges for students learning Traditional Chinese due to its logographic writing system without direct sound–script correlation [2]. This lack of phonetic cues creates more difficulties for students with dyslexia to learn Traditional Chinese, resulting in slower reading, decreased motivation, and increased stress, which negatively affects their academic performance and social development [3].

Early intervention is crucial for students with dyslexia, as it can mitigate the adverse effects on learning and reduce the risk of long-term academic and socioemotional consequences [4]. Research has demonstrated that interventions provided before age six are most effective [2], as this is a critical period for language development. Early intervention strategies, such as tailored instruction, multisensory teaching approaches, and targeted support, can significantly improve the reading, writing, and comprehension skills of students with dyslexia [5]. Moreover, early identification and intervention can boost self-esteem, enhance motivation, and foster a positive learning environment for the concerned students [6].

Unfortunately, limited resources, lack of awareness, and inadequate educator training [7] hinder timely assessments and interventions for students with dyslexia. In addition, the existing assessment process is often time consuming and costly, leading to delayed diagnosis and support beyond the critical period for early intervention [8]. The scarcity of standardized assessment tools tailored for Traditional Chinese learners worsens the challenge of identifying dyslexia accurately and efficiently [9]. Consequently, many students with dyslexia struggle academically and emotionally without the necessary support to overcome their learning difficulties [10].

Information technology has the potential to revolutionize the prescreening process for dyslexia, making it more accessible, efficient, and accurate. By leveraging advancements in data analytics and human–computer interaction techniques, automatic prescreening tools can quickly and effectively identify students at risk of dyslexia [11]. These tools can be easily integrated into educational settings, enabling timely interventions and support from educators and special education coordinators (SENCOs). Furthermore, embedding the gamified environment into the prescreening tools can enhance student engagement and motivation, promoting self-directed learning and reducing the stigma associated with dyslexia assessment [12]. Finally, integrating information technology in the prescreening process can help narrow the gap between early identification and intervention for students with dyslexia, improving their academic outcomes and overall well-being. However, the existing tools cannot tackle the above issues for students learning Traditional Chinese because the prescreening is either done manually (difficult to scale) or partially language dependent (does not cover the linguistic characteristics important for Chinese) and sometimes even language

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independent. Therefore, there is a critical need to develop an automatic prescreening system that can rapidly identify students at risk of dyslexia, enabling timely intervention and support.

In this article, we propose the automatic dyslexia prescreening system (ADPS), a game-based tool designed to identify students at risk of dyslexia quickly and effectively while learning Traditional Chinese. This study aims to address the research question: How effective is the developed gamified tool in prescreening students with dyslexia in Traditional Chinese?

The study contributes to both the theoretical and practical aspects of dyslexia identification and support. The ADPS employs a two-stage approach incorporating linguistic characteristics [i.e., orthographic awareness (OA), morphological awareness (MA), phonological awareness (PA), handwriting (HW), working memory (WM), and vocabulary knowledge (VK)] and interactive design elements, tackling the challenges faced by students with dyslexia in learning Traditional Chinese language acquisition. The first stage focuses on game development based on the design of learning model (DLM) and linguistic characteristics of dyslexia symptoms, and the second stage provides tests to students (a control group and an experimental group) for a more in-depth analysis of their performance. The gamified nature of the *ADPS* ensures a user-friendly experience, promoting student engagement while reducing the stigma associated with dyslexia assessments. The work evaluates the effectiveness of the ADPS in distinguishing between students with/without dyslexia in the context of learning Traditional Chinese. The results demonstrate the tool's potential as an efficient, accurate, and engaging prescreening method for early dyslexia identification. In addition, our findings contribute to the understanding of the unique population in Hong Kong, who speak Cantonese and write Traditional Chinese, which is distinguishable from the people in Guangzhou (Written: Simplified Chinese and Oral: Cantonese) and Taiwan (Written: Traditional Chinese and Oral: Mandarin). In conclusion, this study offers valuable insights into developing and implementing a game-based prescreening tool for dyslexia in Traditional Chinese. The main contributions of this work are as follows.

1) We developed the ADPS, an efficient prescreening tool for identifying students with dyslexia in Traditional Chinese, utilizing six linguistic characteristics.
2) With user-friendly design elements, the ADPS can engage students and enable them to complete prescreening independently without technology literacy issues.
3) It was shown that transposition may not be an effective indicator for prescreening students with dyslexia, as it is uncommon in Chinese characters.
4) The study revealed that Chinese students with dyslexia generally struggle with VK, MA, and OA. Educators can assist these students by focusing on building a solid vocabulary foundation.

The rest of this article is organized as follows. Section II reviews the related works on nonlinguistic-based and linguistic-based prescreening tools. Section III describes the design principles (see Section III-A) and linguistic characteristics (see Section III-B) in the development stage, discusses the gamified environment (see Section III-C), and overviews the user study in the testing stage (see Section III-D). Section IV analyzes the prescreening result and reports the observations. Section V discusses the prescreening performance, linguistic characteristics, gamified environments and motivation, and limitations. Finally, Section VI concludes this article.

II. Literature Review

A. Dyslexia and Its Characteristics

Dyslexia is a neurodevelopmental disorder affecting an individual's ability to read, write, and spell [13]. Critical characteristics of dyslexia include phonological processing difficulties, which hinder decoding written words and mapping sounds to letters [14]; reading difficulties, resulting in slower and less accurate reading; spelling and writing challenges due to trouble connecting sounds to appropriate letters [15]; and WM and executive function deficits that affect overall academic performance and daily life [1]. Dyslexia manifests differently among individuals and is unrelated to intelligence or motivation [16]. Early identification and intervention can help individuals with dyslexia develop compelling reading and writing strategies, enabling academic and professional success.

B. Challenges of Learning Traditional Chinese by Students With Dyslexia

Learning Traditional Chinese poses unique challenges for students with dyslexia due to its logographic writing system, which lacks direct sound–script correlation [17]. Without the phonetic cues in alphabetic languages, students with dyslexia struggle to recognize and memorize characters, leading to a slower reading pace and limited vocabulary development [18]. These challenges exacerbate the inherent difficulties associated with dyslexia, making it even more crucial for educators to provide interventions.

C. Existing Assessment Methods for Dyslexia

The existing assessment methods for dyslexia primarily focus on identifying the underlying cognitive and linguistic challenges associated with the disorder. Table I shows the existing assessments, which can be categorized based on the concerned language, such as Traditional Chinese, Simplified Chinese, and alphabets, including Spanish, English, and Bahasa Malay.

1) Traditional Chinese Scripts: Existing works on dyslexia prescreening for Traditional Chinese scripts have diversified focuses, such as OA and MA. For example, Cheng-Lai et al. [19] measured the relationships between orthographic knowledge and perceptual–motor skills with Traditional Chinese characters. The results revealed that: 1) HW speed is related to deficits in rapid automatic naming (RAN) and 2) visual–motor integration is reflected by the number of characters exceeding the grid limits and the variability of character size. McBride-Chang et al. [20] measured cognitive skills, including syllable awareness, tone deletion, RAN, visual skills, and MA. It was shown that word recognition is linked to MA, tone deletion, and visual skills. Moreover, Wong et al. [21] discovered that at-risk students with dyslexia are slower in RAN and weaker in MA and Chinese character recognition than students without dyslexia.

TABLE I
EXISTING PRESCREENING TOOLS

Item	Author	Aim	Language	GB	OA	MA	PA	HW	WM	VK
1	Lam et al. [30]	To assess the Chinese handwriting performance of students with/without dyslexia	Traditional Chinese	x	x	x	x	v	x	x
2	Mcbride et al. [24]	To investigate copying skills in relation to word reading and writing in Chinese children with/without dyslexia.	Traditional Chinese	x	v	v	x	v	x	x
3	Cheng-Lai et al. [19]	To measure the relationships with orthographic knowledge and perceptual-motor skills with Traditional Chinese characters.	Traditional Chinese	x	v	x	x	v	x	x
4	McBride-Chang [20]	To measure the cognitive skills, including syllable awareness, tone deletion, RAN, visual skill, and morphological awareness.	Traditional Chinese	x	x	v	v	x	v	x
5	Lin et al. [23]	To investigate the prevalence rate of children with dyslexia, and to evaluate their Chinese reading ability.	Simplified Chinese	x	v	v	v	x	x	v
6	Shu et al. [31]	To understand Chinese reading development and impairment with nine cognitive constructs.	Simplified Chinese	x	x	v	v	x	x	v
7	Huang et al. [22]	To develop a Chinese Reading Ability Test for Chinese primary students who speak Mandarin.	Simplified Chinese	x	v	v	v	x	v	x
8	Rello et al. [32]	To design an online gamified test and a predictive machine model for easier dyslexia learning detection.	Spanish	v	v	v	v	x	v	x
9	Rauschenberger et al. [33]	To screen students with dyslexia using new indicators related to motor skills.	Spanish	v	x	x	x	x	x	x
10	Rello et al. [34]	To observe how people interact with a linguistic computer-based game.	English	v	v	v	v	x	x	x
11	Ekhsan et al. [29]	To develop a computer-based screening tool by implementing multimedia elements that suitable for dyslexic students.	Bahasa Malaysia	v	v	x	v	x	x	x
12	ADPS (Our work)	To provide a quick test to identify at-risk children based on linguistic characteristics with gamified tool based.	Traditional Chinese	v	v	v	v	v	v	v

The acronyms GB, OA, MA, PA, HW, WM, and VK denote gamified-based, orthographic awareness, morphological awareness, phonological awareness, handwriting, working memory, and vocabulary knowledge, respectively.

2) Simplified Chinese Scripts: Most of the existing works on dyslexia prescreening for Simplified Chinese scripts focused on VK and MA. For example, Huang et al. [22] developed a Chinese Reading Ability Test for Mandarin-speaking primary students. The test included character recognition, PA (i.e., onset and rhyme), MA (i.e., five Chinese compounding structures), RAN (i.e., numbers), OA (i.e., noncharacter recognition), and reading ability measures (i.e., word reading fluency). Lin et al. [23] developed a screening test to measure students' performance in vocabulary, Chinese reading ability, and audiovisual integration, highlighting that simplified Chinese scripts are more prevalent than Traditional Chinese scripts due to the complexity of Traditional Chinese characters. Some existing works also considered HW practice, as it may elaborate on orthographic representation [24].

Relationship between two scripts: Up to 60% of frequently used Traditional and Simplified Chinese characters share the same form [25], such as 大 (lit. big), and both the scripts follow the same writing rules. Therefore, the HW, copying skills, and space concepts could be adopted by two scripts. However, some Simplified Chinese characters may present challenges in maintaining consistent orthographic representations compared to their traditional counterparts. For example, the Simplified Chinese character for "love" (爱) lacks the "heart" (心) component in the Traditional Chinese character (愛). In addition, multiple Traditional Chinese characters are often Simplified into a single Simplified Chinese character, leading to confusion about the meaning of words [26]. For example, the Simplified Chinese character "发" is the same in the words "头发" (lit. hair) and "发财" (lit. get rich). However, the original forms in Traditional Chinese are different, namely, "頭髮" (lit. hair) and "發財" (lit. get rich). Therefore, when a Simplified character is recovered from its traditional counterpart, it is easier to identify its meaning. However, students with dyslexia may encounter difficulties in language-relevant content, making dyslexia prescreening with language-relevant content more suitable in the context of Traditional Chinese [27].

3) Alphabets: Prominent literature on dyslexia prescreening for alphabet languages often adopts a gamified- based approach and is less dependent on language content. For example, Rauschenberger et al. [28] screened students with dyslexia using a web game and language-independent content and highlighted that nonlanguage content could facilitate early intervention for pre-readers with no language skills. In addition, Ekhsan et al. [29] developed a multimedia application to screen students with dyslexia. They emphasized that multimedia elements are suitable for prescreening students with dyslexia and provide an alternative to manual screening.

In summary, these assessment methods provide valuable insights into how students' strengths and weaknesses in specific areas can be utilized for dyslexia screening, such as HW performance, copying skills, VK, MA, RAN, and vocabulary skills [30], [31], [23]. The multimedia approach could also effectively engage children's concentration while providing an enjoyable and exciting experience.

D. Gamified Environment and Its Benefits

A gamified environment with an interactive and multimedia approach has been discovered to effectively capture children's attention while offering an enjoyable and thrilling experience [35], [36]. The gamified environment is an innovative educational approach incorporating game elements and design principles, such as performance measurement (badges, level, and dashboards), novelty (new game elements), and sensation (visual or sound stimulation) [37], [38], into the learning process, aiming to increase engagement, motivation, and learning outcomes [39], [40]. In addition, a gamified environment can create a sense of enjoyment for students during prescreening, leading to the unconscious acquisition of knowledge and skills [41]. Furthermore, incorporating animated effects and interactive designs can enhance the effectiveness of the prescreening, as they captivate and inspire students [42]. By integrating interactive experiences, the gamified environment could encourage active participation and increase motivation [43], [44]. Also, intrinsic motivation can lead to improved retention and consolidation of knowledge [45].

E. Limitations of the Existing prescreening Tools

The existing prescreening tools for dyslexia aid in early identification of at-risk students, facilitating timely interventions, and raising awareness between educators and parents. These tools often incorporate standardized tests, questionnaires, or computer-based assessments focusing on dyslexia-related skills, such as PA, decoding, and reading fluency. By identifying potential challenges early, educators can implement targeted support strategies to address students' specific needs, improving their academic performance and overall well-being.

However, they fail to capture all the characteristics of dyslexia, including HW, OA, MA, PA, WM, and VK (i.e., six linguistic characteristics). Also, some traditional assessments rely on the expertise of trained professionals and are human resource intensive. Limited access to resources and funding can also hinder the adoption and implementation of prescreening tools. Consequently, it is essential to develop more inclusive, accessible, and accurate prescreening tools to support better the early identification and intervention efforts of students with dyslexia. Furthermore, a gamified environment can enhance engagement and motivation in the prescreening tests.

F. Improvement Upon Existing Methods

This work improves the existing approaches by incorporating six key linguistic skills with gamified environments for identifying dyslexia in the Chinese context. First, the tool measures Chinese OA, focusing on character recognition. Second, it assesses MA in Chinese by manipulating morphemes. Third, we evaluate PA using Cantonese, the phonetic system prevalent in Hong Kong, to cater to local requirements. Fourth, the proposed tool examines Traditional Chinese HW skills, concentrating on stroke formation, spacing, and character writing, which may reveal underlying dyslexic traits. Furthermore, we assess WM within the context of Chinese language processing, considering the unique demands of recognizing similar characters and reading sentences. Finally, the proposed tool evaluates Chinese VK, addressing word recognition and formation challenges that could indicate dyslexic traits.

III. Application Design

This study has two stages. In the development stage, experts from different fields collaborated to develop the gamified prescreening tool to bridge the gap between engineering and education. The research team comprises university professors specializing in dyslexia, education research, and integrated system design. The objective is to develop a novel gamified tool, the ADPS, to prescreen at-risk students with dyslexia. The design of ADPS was based on an empirical analysis of errors. Specifically, students' Chinese writings were collected, and their mistakes were annotated with general linguistic characteristics (details will be discussed in Section III-B), including OA, MA, PA, HW, WM, and VK. These mistakes reflect specific difficulties associated with dyslexia and are utilized for dyslexia prescreening.

A. Development Stage: Design Principles

Gamification has demonstrated evidence of great potential in educational technology. Gamification is becoming increasingly popular, particularly in creating gamified designs that motivate students to learn [46]. According to Huang and Soman [47], gamified designs directly affect motivation, which is crucial for students' effective use of learning methods [48]. Saputra and Risqi [35] designed a learning model—DLM—to improve students' learning motivation by using gamification elements. The design principles utilized in this study are as follows.

1) Design of Learning Model: The DLM consists of three phases, including Phase 1: motivational affordances (Game elements), Phase 2: psychological outcomes, and Phase 3: behavioral outcomes. Several motivational affordances are represented by game elements, including: 1) story, clear goals, and levels; 2) points, rewards, and feedback; and 3) achievement/badges. According to the DLM, all the game elements need to follow a

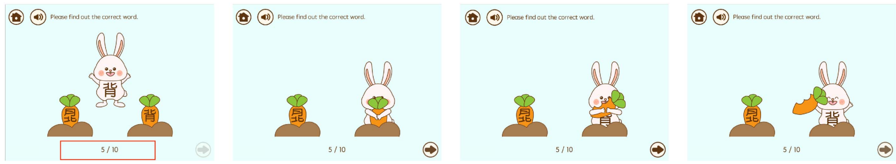

Fig. 1. Game (Set 2, Game 5) comprises a story and clear goals. The red boxes indicate how many questions students need to complete and how many questions are left. The animation of "rabbit eats carrots" notifies students that they have finished a task.

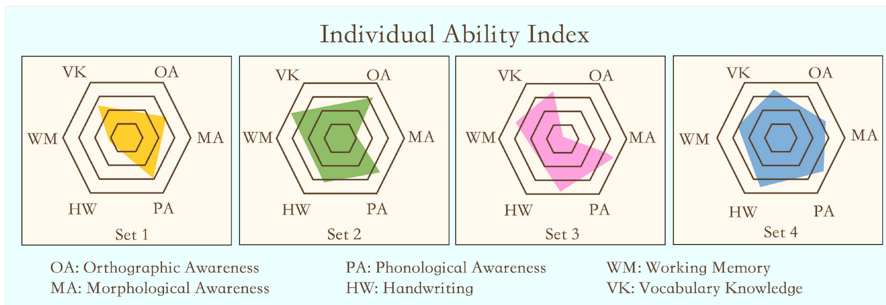

Fig. 2. Radar images indicate the individual performance for each linguistic factor. One radar image corresponds to students' performance in one prescreening test.

consistent set of rules, aiming to produce specific psychological effects. The primary objective is to foster engagement, which generates interest in playing the games. Once this goal is accomplished, the following objectives are to promote enjoyment and motivation, encouraging students to participate in the learning process. The details of the three phases and their application in this study are as follows.

Phase 1: motivational affordances form the foundation of students' learning experience. It comprises a story, clear goals, and difficulty levels that help students comprehend the learning objectives and context and choose a suitable difficulty level. This information is intended to capture students' attention and generate their interest in the subject [49]. Each game element is designed to create specific psychological effects. An intriguing and captivating plot can capture students' attention, promoting engagement and enjoyment. Clear goals and an exciting story can motivate students to achieve the learning objectives [50]. Different difficulty levels are designed to build learning momentum, and students experience a sense of accomplishment as they progress through all the available levels. Students receive points, rewards, and feedback in *Phase 2: psychological outcomes*. The points and rewards aim to provide students with continuous encouragement and motivation throughout the learning process [51]. For each minor accomplishment, students will receive a point or reward. Feedback should always be positive, regardless of whether they achieve a high or low score, to prevent negative experiences and motivate students to continue learning. The badge is granted upon achieving specific goals in *Phase 3: behavioral outcomes*. The badge boosts students' morale and inspires them to strive for further accomplishments [52].

The prescreening tool's user interface (UI) design developed in this study was also based on the *DLM*. In *Phase 1*, each game contained a story and distinct objectives. A sample game is illustrated in Fig. 1, where a rabbit locates the appropriate carrot with the same Chinese character as the one on its body. Once the rabbit located the correct carrot, it could consume it joyfully. The game also displayed students' progress at the bottom of the screen, informing students that they had five more questions to complete at this level. In *Phase 2*, each set of prescreening games included a point-and-reward system. Fig. 2 illustrates four radar images, which indicate the individual performance for each linguistic factor, where one radar image corresponds to students' performance in one set of prescreening games. In *Phase 3*, students were awarded a badge upon accomplishing particular objectives, such as finishing prescreening games. Fig. 3 showcases the badges, which ranged from copper medals to stars, symbolizing the completion of Sets 1–4. Upon finishing the fourth set, a large trophy appeared, accompanied by celebratory music and a character with clapping animation, to commend and motivate the students.

B. Development Stage: Linguistic Characteristics

This section annotates the popular mistakes encountered by students with dyslexia in six linguistic characteristics that are associated with dyslexia, including: 1) OA; 2) MA; 3) PA; 4) HW; 5) WM; and 6) VK.

1) Orthographic Awareness: OA in Chinese refers to understanding conventions and rules for Chinese characters [53], which plays an essential role in Chinese reading and is a core deficit of dyslexia [54]. OA in English pertains to recognizing letter patterns, whereas in Chinese, it involves understanding the rules and conventions for Chinese characters. It enables us to recognize familiar letter patterns. For example, an individual with good OA will recognize "down" in "rundown." Chinese orthography has graphical and functional properties, with radicals serving the purpose of conveying pronunciation and meaning. The radicals also convey the pronunciation and

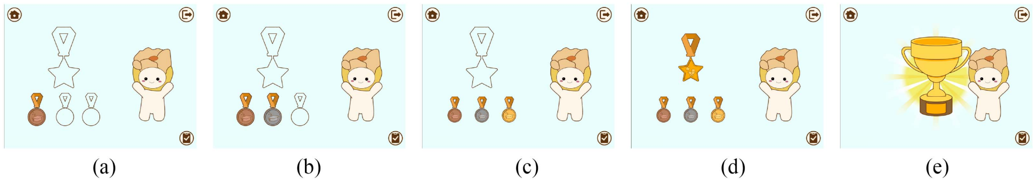

Fig. 3. Badges demonstrate students' progress. After completing a prescreening test, students would receive a badge. After students complete the four tests, they are awarded four badges and a trophy. This is a gamified environment to encourage students' active participation. (a) Bronze Award. (b) Silver Award. (c) Gold Award. (d) Grand Award. (e) A Champion Trophy.

meaning of the characters they are a part of [55]. For example, the compound character 晴 (lit.: cloudless; Cantonese: cing4) has a left–right structure and consists of two components: 日 (lit.: day; Cantonese: jat6) and 青 (lit.: blue; Cantonese: cing1). The left component 日 is a semantic radical that indicates the related meaning of the character, and the component on the right 青 is a phonological radical that cues the sound (i.e., cing1 to cing4). Research shows that awareness strongly correlates with Chinese literacy development, particularly in reading proficiency [56] and comprehension [57]. Therefore, incorporating this awareness in the prescreening tool can be beneficial.

2) Morphological Awareness: MA involves reflecting on and manipulating the smallest meaningful units in language, and it is essential for language development [58]. Elbro and Arnbak [59] found that people with dyslexia can read morphologically simple words but have difficulty reading complex words. In English, MA includes derivational (e.g., connect and connection) and inflectional morphology (e.g., go and going), which enriches vocabulary and develops grammatical accuracy [60]. MA uniquely contributes to character recognition, writing, reading fluency, and comprehension in Chinese. Morphemes in Chinese refer to the building blocks of characters, which develop the relationship between form and meaning [31], such as a basketball (籃球, laam4 kau4) and the color blue (藍色, laam4 sik1). A few studies have also explored the relationship between MA and gamified digital environments and show that games can be designed to test MA [58]. Incorporating MA in a gamified digital environment can help students develop the complex relationship between form and meaning.

3) Phonological Awareness: PA refers to a person's sensitivity to the phonological structure of spoken language [61]. Snowling [62] found that deficits in PA are a major cause of reading failure in dyslexia, and phonological difficulties persist throughout the development from preschool to adulthood. In English, PA is closely related to literacy and includes phonemic awareness, the ability to manipulate individual sounds in words. For instance, someone with good PA can distinguish between the words "bay" and "pay." However, Chinese is a logographeme system, which is different from the Latin languages' alphabet system. PA in Chinese involves recognizing and manipulating sound units with multiple levels of phonetic units, such as syllables and phonemes [63]. The syllable deletion method has been successfully used to assess PA in Chinese, where participants are required to say the word without one syllable [64]. For example, participants were required to say 火車站 (fo2 ce1 zaam6) without 火 (fo2), where they were expected to say 車站 (ce1 zaam6). PA is crucial for learning to read [65], particularly in Chinese, where over 80% of characters are semantic–phonetic compounds [66]. Character's meaning, sound, and structure are essential for recognition and memorization [67]. Identifying mispronunciations and RAN are essential to acquiring this awareness [68], [69]. While some tests have been created for mispronunciation detection, limited research has been done on form–sound matching, word pronunciation and meaning confusion, and identifying characters with similar sounds but different meanings. This study aims to fill this gap by designing PA-based prescreening in a digital learning environment.

4) Handwriting: HW is one of the core symptoms that significantly affect people with dyslexia [70]. The difficulty with HW can manifest in different forms, such as poorer legibility [71], larger script size [72], excessive spacing [13], inconsistent spatial orientation [73], and longer writing time [74]. In English, students are usually required to write words on horizontal grid lines. Some common writing characteristics of students with dyslexia include many spelling errors, inability to complete the written tasks [75], or failure to complete written tasks within a given time [76]. Chinese characters are written within a square grid, and their visual complexity [77] is high due to many radicals and strokes in their structure. Elaboration of HW through orthographic representations and formation of motor memory is a common strategy for mastering Chinese reading [78]. For example, 木 (wood), 林 (forest), and 杏 (apricot) share the same component 木(wood), but the character structures are different. HW problems in Chinese are more related to dyslexia than in alphabetic languages, such as English [79], as characters with similar components can have different structures.

5) Working Memory: WM is a memory system with limited capacity that involves temporary storage and processing of information [80]. Impaired WM is a defining symptom of dyslexia and can significantly impact individuals with dyslexia [81]. Reading or sentence span tasks are suitable measures of WM function, requiring speech processing and selection from the central executive [82]. Low WM capacity leads to reading, spelling, and dictation deficits in students with dyslexia [83]. In English, students with dyslexia make more spelling, punctuation, and capitalization errors and omit more words in dictation tasks [84]. Similar WM tests have been conducted in Chinese, but the lack of sound–script correspondences between phonology and orthography may not directly affect students' performance [85]. Unlike the previous paper-based tools, we designed a gamified digital prescreening tool to address this gap in the gamified environment.

6) Vocabulary Knowledge: VK is recognized as a strong predictor of dyslexia symptoms in reading fluency [86], which has two dimensions: breadth (how many words are known) [87] and depth (how well the meanings are known) [88]. For example,

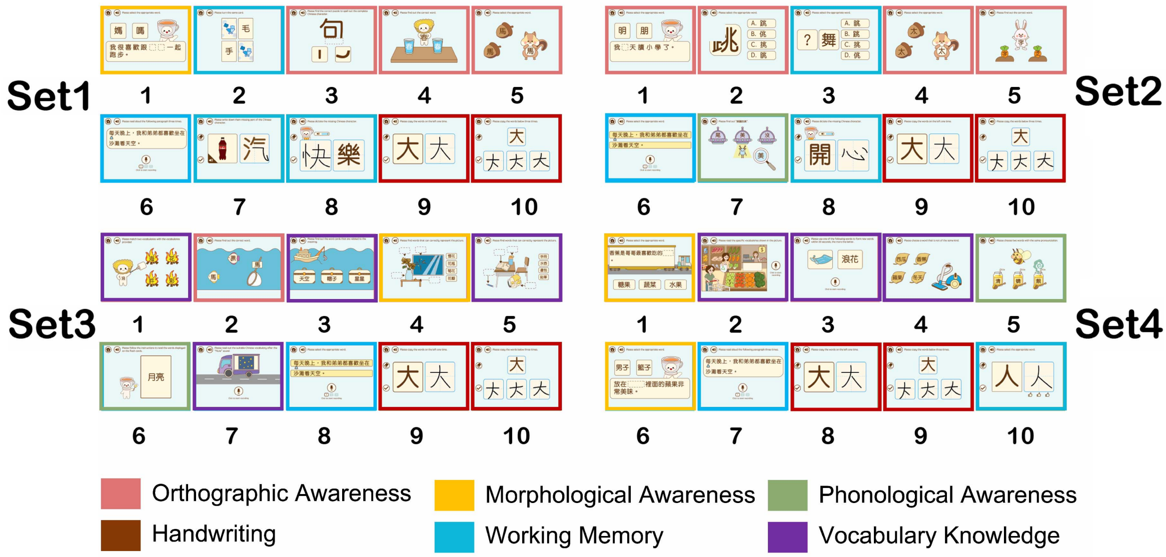

Fig. 4. Linguistic characteristics related design of four prescreening tests. Each set covers different linguistic contents, and the level of difficulty increases incrementally. The descriptions of gamified design are given in Section III-C.

if a student looks at a picture of a cat, the student can name it 貓 (maau1) in Cantonese. The depth of knowledge relates to individual lexical aspects (i.e., a rich network of associations around a word) [88]. For example, when a student looks at 貓 (cat), the student can associate it with 小貓 (kitten), 熊貓 (panda), 貓頭鷹 (owl), and 花面貓 (a man with dirty face). Students with dyslexia have difficulties in Chinese VK, as shown by previous studies [89]. However, using a single measure of vocabulary is not enough, as some students may recognize words in a picture format but not in a written form. This study addresses this gap by adopting both the breadth and depth dimensions for prescreening students with dyslexia in a gamified digital environment.

C. Gamified Environments

Fig. 4 shows the practical implementation of the gamified environment. The content design is based on linguistic characteristics, and the UI design is based on the *DLM* (see Section III-A). The prescreening system included four sets of tests, each with ten games. A detailed description of the four sets of games and the corresponding linguistic characteristics to be tested is shown as follows.

Set 1:

1) *Game 1* applied the drag-and-drop approach and examined if students could differentiate similar Chinese characters with the same sound (characteristics tested: MA).
2) *Game 2* was a matching game and tested students' memory of the same Chinese character (characteristics tested: WM).
3) *Game 3* utilized the drag-and-drop approach and evaluated students' ability to recognize wrong components (characteristics tested: OA).
4) *Game 4* analyzed whether students could identify the Chinese characters by stroke addition (characteristics tested: OA).
5) *Game 5* scrutinized if students could distinguish the Chinese characters by stroke deletion (characteristics tested: OA).
6) *Game 6* was a reading task to check students' reading fluency (characteristics tested: WM).
7) *Game 7* was a writing test to understand students' stroke concepts by writing one component of a word (characteristics tested: WM).
8) *Game 8* was a pre-dictation. Students were requested to dictate the first word of a vocabulary (characteristics tested: WM).
9) *Game 9* was a one-word copying test with single (e.g., 木) and left–right (e.g., 好) structures to assess students' space concept (characteristics tested: HW).
10) *Game 10* was a three-word copying task with a single and left–right structure to evaluate students' character construction awareness (characteristics tested: HW).

Set 2:

1) *Game 1* applied the drag-and-drop approach and examined if students could differentiate similar Chinese characters (characteristics tested: OA).
2) *Game 2* was a matching game that gave students visual cues to find the right word from similar Chinese characters (characteristics tested: OA).
3) *Game 3* was a matching game and requested students to form a correct vocabulary from similar Chinese characters (characteristics tested: OA).
4) *Game 4* tested if students could distinguish the correct characters from the reversal of Chinese characters (characteristics tested: OA).
5) *Game 5* scrutinized if students could distinguish the correct characters from their rotation (characteristics tested: OA).
6) *Game 6* was a reading task to check students' reading fluency (characteristics tested: OA).

7) *Game 7* checked if students could identify Chinese characters with similar sounds but different meanings (characteristics tested: PA).
8) *Game 8* was a post-dictation. Students were requested to dictate the second word of a vocabulary (characteristics tested: OA).
9) *Game 9* was a one-word copying test with left–right and up–down (e.g., 吉) structure to assess students' space concept (characteristics tested: HW).
10) *Game 10* was a three-word copying task with left–right and up–down structure to evaluate students' word formation awareness (characteristics tested: HW).

Set 3:

1) *Game 1* tested students' MA for words with the same sound (characteristics tested: VK).
2) *Game 2* examined students' ability to identify the transposition of Chinese characters (characteristics tested: OA).
3) *Game 3* reviewed students' ability to identify same-nature vocabularies (characteristics tested: VK).
4) *Game 4* was a matching task to understand students' MA (characteristics tested: MA).
5) *Game 5* was a matching task to assess students' vocabulary identification ability (characteristics tested: VK).
6) *Game 6* was a task of vocabulary recognition (characteristics tested: PA).
7) *Game 7* evaluated students' ability of RAN (characteristics tested: VK).
8) *Game 8* was a reading task to check students' reading fluency (characteristics tested: OA).
9) *Game 9* was a one-word copying test with left-up-down (e.g., 陪) and left-middle-right (e.g., 樹) structure to assess students' space concept (characteristics tested: HW).
10) *Game 10* was a three-word copying task with left-up-down and left-middle-right structure to evaluate students' word formation awareness (characteristics tested: HW).

Set 4:

1) *Game 1* evaluated students' ability to distinguish word meaning (characteristics tested: MA).
2) *Game 2* was a task to assess students' vocabulary size (characteristics tested: VK).
3) *Game 3* was a task to examine students' ability of vocabulary expansion (characteristics tested: VK).
4) *Game 4* reviewed students' ability to do odd-man-out tasks (characteristics tested: VK).
5) *Game 5* tested students' ability in form–sound matching (characteristics tested: PA).
6) *Game 6* evaluated if students were affected by the pronunciation of words and confused by word meaning and form (characteristics tested: MA).
7) *Game 7* checked students' reading fluency (characteristics tested: OA).
8) *Game 8* was a one-word copying test with semi- (e.g., 包) and full-enclosed (e.g., 固) structure to assess students' space concept (characteristics tested: HW).
9) *Game 9* was a three-word copying task with a single and left-right structure to evaluate students' word formation awareness (characteristics tested: HW).
10) *Game 10* was a task of "Look-say-cover-write-check" to test students' memory (characteristics tested: OA).

Each game consisted of five mini-games and one validation game. The validation game was randomly selected from the five mini-games. All the game contents were in level one, which was based on the study of the Chinese Characters recommended for the subject of Chinese Language in Primary Schools,[1] and designed by a local research team [72]. The difficulty of the four sets of games increases substantially. In addition, the gamified environment employed large icons with all the instructions supporting the text-to-speech (TTS) function, as shown in Fig. 5. The app was developed using Unity and could run on tablets, such as iPad Air.

D. Testing Stage: User Study

A user study was conducted from February 2022 to December 2022. The participants were recruited based on purposeful sampling. This sampling technique is widely used in qualitative research to identify and select informative cases [90]. In this study, students in the control group were without any symptoms of dyslexia, and students in the experimental group were with dyslexia. The criteria for recruiting participants are: 1) studying in grades 1–3; 2) being able to read and write Traditional Chinese characters and speak Cantonese; and 3) having no other medical or physical disabilities that might interfere with their HW ability and reading aloud ability. Also, all the students had experience using tablets.

1) Regulations: This study followed the following regulations: 1) informed consent was obtained from the student's parents before running the experiment; 2) participation was entirely voluntary and based on consent; and 3) the University's Institutional Review Board approved the experimental protocol (Number: HREP2022-0276).

2) Participants: The participants were 62 students (27 females and 35 males) aged 7–9 (average age is 8.340 with a 0.655 standard deviation) from a local primary school in Hong Kong. 30 of them have dyslexia, and 32 have no dyslexia identified.

3) Study Method: Each participant was enrolled in the ADPS test for four days and was required to play one set of tests daily. Each test took 30 min, with the difficulty level increasing incrementally.

4) Procedures: Before the test, students had a 5-min face-to-face (F2F) training, instructing them on the function of each button. One instructor provided technical support to two students (as shown in Fig. 6). Then, the instructors assisted students to log in to the app. As shown in Fig. 7, students conducted the prescreening. Prior to the commencement of each game, the app provided a game demo, ensuring that every student was acquainted with the gameplay mechanics. After that, students conducted the prescreening games, and the app uploaded the results and interaction data, such as the start/end times and answer

[1] [Online]. Available: https://ephpth.ephhk.com/resource/tools/lcprichi/

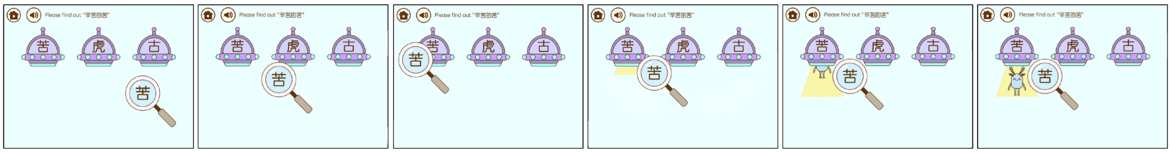

Fig. 5. Gamified environment employs large icons with instructions that support the TTS function. This game utilizes the animation of "finding alien" to attract students' attention (Set 2, Game 7).

Fig. 6. Pilot test was conducted in a classroom setting. Participants were working on the prescreening game.

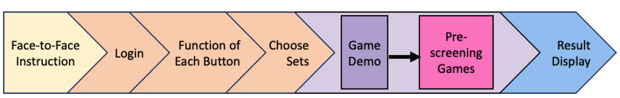

Fig. 7. Overview of the study procedure. The yellow bow indicates the preparation task for participants, while the orange boxes denote device-based user activities primarily in the preparation stage. The core prescreening materials are enclosed within the purple-colored frame, and the rightmost box in blue depicts the meta activity.

choices, to the cloud server. Finally, students could review their performance. After each test, the instructor interviewed students by asking some open-ended questions. The interview typically lasted 5 min and was recorded manually.

IV. Data Analysis

We constructed a database to gather user data from the prescreening tool for data analysis. The data encompass the correctness rate, answer time, and HW images. Regarding the time spent, the start time is logged when participants initiate the game by clicking the game icon, and the end time is recorded when participants press the completion icon to conclude the game.

A. Evaluation Metrics

Each set consisted of ten games. Each game included five mini-games. Except for HW, all other games had the same weight, i.e., one point per mini-game. The evaluation metrics of HW were shown as follows:

Handwriting: The grading criteria were adapted from [52] and [91], which were used in the same district (see Fig. 8).

1) *Label 1 (Noncharacters):* A significant part of compound characters consists of graffiti or only the radicals.
2) *Label 2 (Directionality):* A portion of the characters or the entire character is a mirror character.

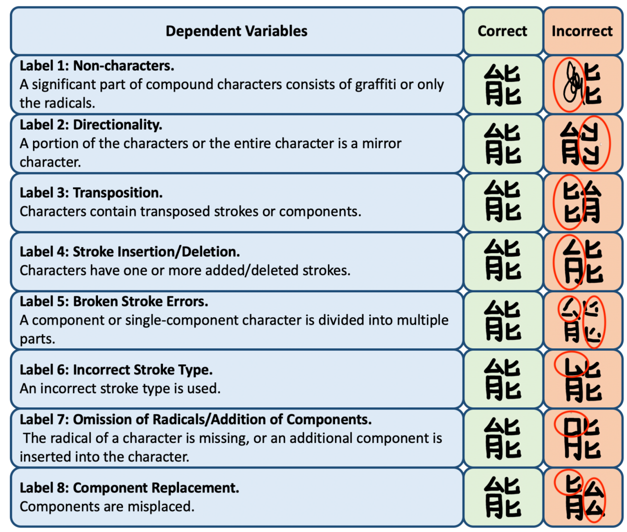

Fig. 8. HW grading criteria consist of eight common mistakes.

3) *Label 3 (Transposition):* Characters contain transposed strokes or components.
4) *Label 4 (Stroke insertion/deletion):* Characters have one or more added/deleted strokes.
5) *Label 5 (Broken stroke errors):* A component or single-component character is divided into multiple parts.
6) *Label 6 (Incorrect stroke type):* An incorrect stroke type is used.
7) *Label 7 (Omission of radicals/addition of components):* The radical of a character is missing, or an additional component is inserted into the character.
8) *Label 8 (Component replacement):* Components are misplaced.

B. Results of Four Prescreening Sets

In this section, we discuss the prescreening results. SPSS 29.0.1.0 was utilized to process the data. The descriptive and correlation study for four prescreening sets and the associated descriptive and correlation study variables in linguistic characteristics are provided in Tables II and III, respectively.

To answer the research question, a repeated measures analysis of variance (ANOVA) was conducted to assess the differences between groups, as shown in Table II. Students without dyslexia performed significantly better than those with dyslexia. Both average score and time differences in four sets between the two groups were statistically significant. As the difficulty level of the four prescreening sets increases incrementally, the performance of the two groups over the four sets decreases, as shown in

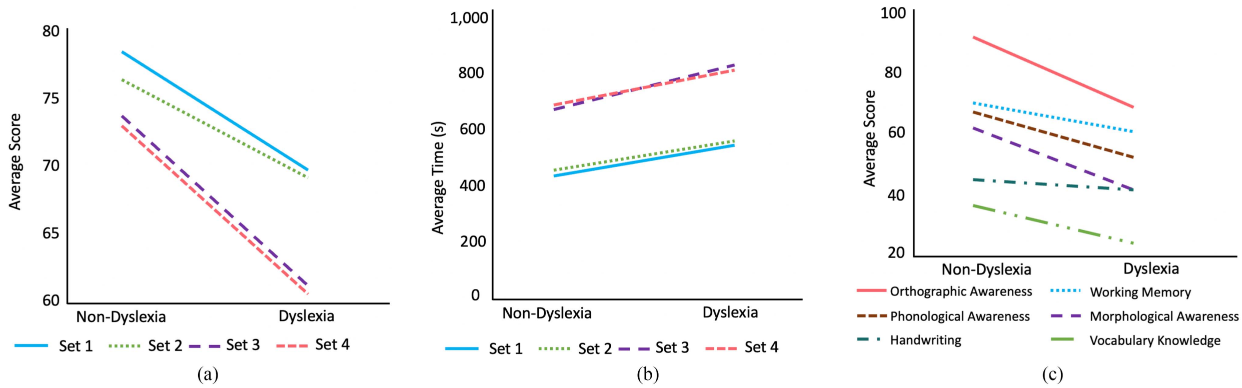

Fig. 9. Performance comparison between two groups of students. (a) Score overview of four sets of prescreening. Performance of both the groups declined as expected as the difficulty level increased incrementally. (b) Time overview of four sets of prescreening. Both the groups exhibited longer completion time for Sets 3 and 4 compared to Sets 1 and 2. (c) Linguistic characteristic overview of two groups of students. Both the groups faced challenges in handwriting and vocabulary due to script complexity and students' vocabulary size.

TABLE II
DESCRIPTIVE AND CORRELATION STUDY IN FOUR SETS

Score							eta	squared		Time				eta	squared	
Set	Group	N	M	SD	F-val	Sig.	η^2	F-val	Sig.	M	SD	F-val	Sig.	η^2	F-val	Sig.
1	ND	32	78.637	4.71	43.335	**	0.419	43.337	**	439.59	147.893	10.429	**	0.148	10.429	**
	Dys	30	69.95	5.663						551.47	122.744					
2	ND	32	76.538	11.355	7.482	***	0.111	7.483	**	462.47	124.899	8.032	**	0.118	8.032	**
	Dys	30	69.303	9.289						566.6	163.01					
3	ND	32	74.02	17.761	8.487	**	0.124	8.487	**	678.75	178.768	8.904	**	0.129	8.904	**
	Dys	30	61.443	16.123						830.27	220.075					
4	ND	32	73.203	11.617	15.377	***	0.204	15.378	**	693	189.591	4.86	*	0.075	4.86	*
	Dys	30	60.881	13.116						819.5	258.955					

Note: *** = p < 0.001, ** = p < 0.01, and * = p < 0.05. The acronyms ND, Dys, and Val are non-dyslexia, dyslexia, and value, respectively.

TABLE III
DESCRIPTIVE AND CORRELATION STUDY VARIABLES IN LINGUISTIC CHARACTERISTICS

Score								eta	squared	
	Group	N	M	Diff.	SD	F-value	Sig.	η^2	F-value	Sig.
OA	ND	32	90.63	29.47%	16.837	17.812	***	0.229	17.812	**
	Dys	30	70		21.496					
MA	ND	32	63.88	41.33%	15.591	25.528	***	0.298	25.528	**
	Dys	30	45.2		13.335					
PA	ND	32	68.44	23.69%	14.449	12.445	***	0.172	12.445	**
	Dys	30	55.33		14.794					
HW	ND	32	48.22	6.38%	8.556	1.741	0.192	0.025	1.537	0.22
	Dys	30	45.33		8.656					
WM	ND	32	71.34	13.60%	7.512	19.543	***	0.245	19.457	***
	Dys	30	62.8		7.703					
VK	ND	32	40.53	38.47%	12.295	15.204	***	0.198	14.831	***
	Dys	30	29.27		10.285					
Time								eta	squared	
	Group	N	M	Diff.	SD	F-value	Sig.	η^2	F-value	Sig.
OA	ND	32	36.84	0.79%	19.286	0.004	0.951	0	0.004	0.951
	Dys	30	37.13		17.234					
MA	ND	32	232.84	14.37%	74.798	2.209	0.142	0.036	2.209	0.142
	Dys	30	266.3		101.247					
PA	ND	32	117.66	7.07%	34.339	0.846	0.361	0.014	0.846	0.361
	Dys	30	125.97		36.821					
HW	ND	32	579.06	40.98%	232.285	8.331	*	0.122	8.331	**
	Dys	30	816.33		398.516					
WM	ND	32	822.34	24.18%	217.061	14.606	***	0.196	14.606	***
	Dys	30	1021.17		190.627					
VK	ND	32	485.06	3.27%	133.175	0.202	0.655	0.003	0.202	0.655
	Dys	30	500.93		145.082					

Note: *** = p < 0.001, ** = p < 0.01, and * = p < 0.05. The acronyms ND, Dys, and Diff. are non-dyslexia, dyslexia, and differences, respectively.

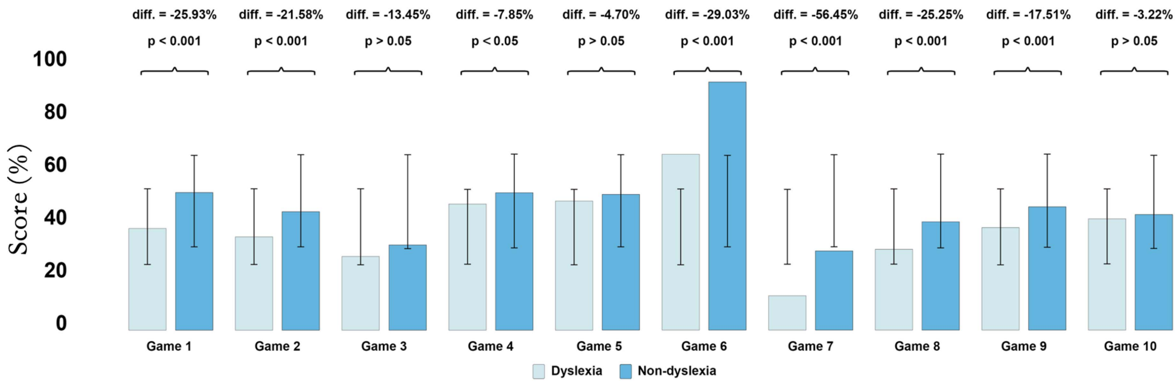

Fig. 10. Score performance of Set 1. Diff. denotes the percentage difference between two groups.

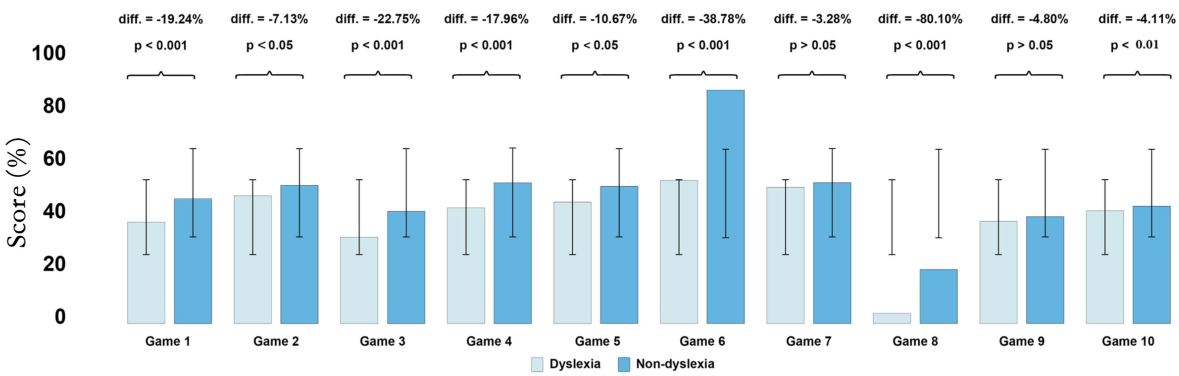

Fig. 11. Score performance of Set 2. Diff. denotes the percentage difference between two groups.

Fig. 9(a). However, the performance of students with dyslexia dropped more significantly than that of those without dyslexia, especially from Sets 2 to 3. Students with dyslexia did poorly in Set 3, because they are weak in VK, and 40% of the questions in Set 3 test VK.

Furthermore, it took longer for students with dyslexia to complete the game. As shown in Fig. 9(b), both the groups spent more time completing Sets 3 and 4 than Sets 1 and 2. The reason is that Sets 3 and 4 involved more diverse questions and focused more on students' VK, which was challenging for both the groups. However, students with dyslexia had a more significant drop in Sets 3 and 4 compared with those without dyslexia.

Surprisingly, the increase in time consumption for both the groups was very close. In addition, we conducted ANOVAs to examine the statistically significant difference between the performance of the two groups. The analysis revealed that students with dyslexia spent much more time finishing the four sets of tests than those without dyslexia, and the result was statistically significant. Therefore, the score and time consumption results indicated that the four sets of prescreening tests could significantly differentiate two groups of students, supporting the research question.

A repeated measures ANOVA was performed to understand how each linguistic characteristic contributes to the differentiation of two groups (refer to Section III-B). The detailed analysis of the performance of the prescreening tests was shown as follows: Set 1 (see Fig. 10), Set 2 (see Fig. 11), Set 3 (see Fig. 12), and Set 4 (see Fig. 13). The analysis is a single-factor ANOVA for the score performance. The *Y*-axis represents the score received, and the *X*-axis represents each game in the tests.

In Set 1 (see Fig. 10), students with dyslexia exhibited a significant weakness in reading fluency (Game 6) and stroke concept (Game 7), which were 29.03% and 56.45% lower than those without dyslexia, respectively. These two games are related to WM. However, the differences were mild in Games 4 and 5 (OA) and Game 10 (HW).

In Set 2 (see Fig. 11), students with dyslexia were significantly weaker in reading fluency (Game 6) and dictation (Game 8), which were 38.78% and 80.10% lower than those without dyslexia, respectively. These two games also belong to WM. However, the differences were mild in Game 2, Game 7, and Game 10, which test OA, PA, and HW, respectively.

In Set 3 (see Fig. 12), students with dyslexia had significant weakness in the same sound word (Game 1), same nature identification (Game 2), MA (Game 4), and vocabulary recognition (Game 6), which were 36.22%, 32.12%, 30.21%, and 37.14% lower than those of without dyslexia, respectively. These four games are associated with VK, OA, MA, and PA, respectively. However, the differences were mild in Game 2 and Game 9, which are about OA and HW.

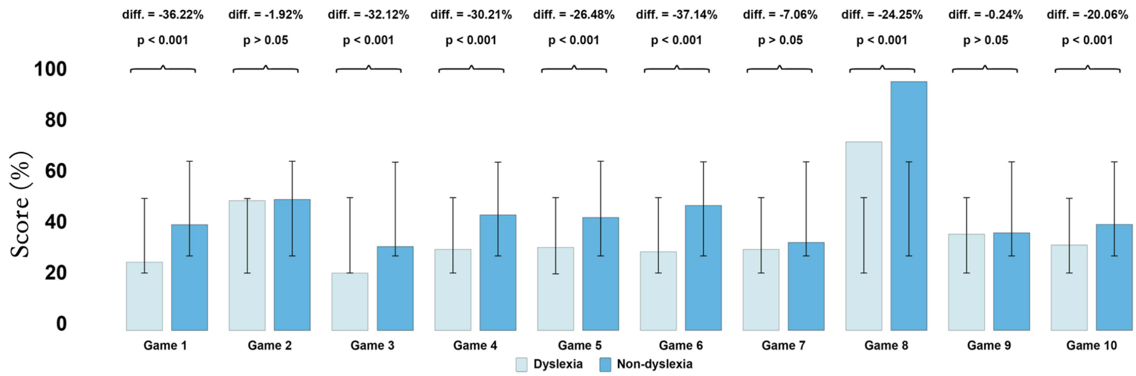

Fig. 12. Score performance of Set 3. Diff. denotes the percentage difference between two groups.

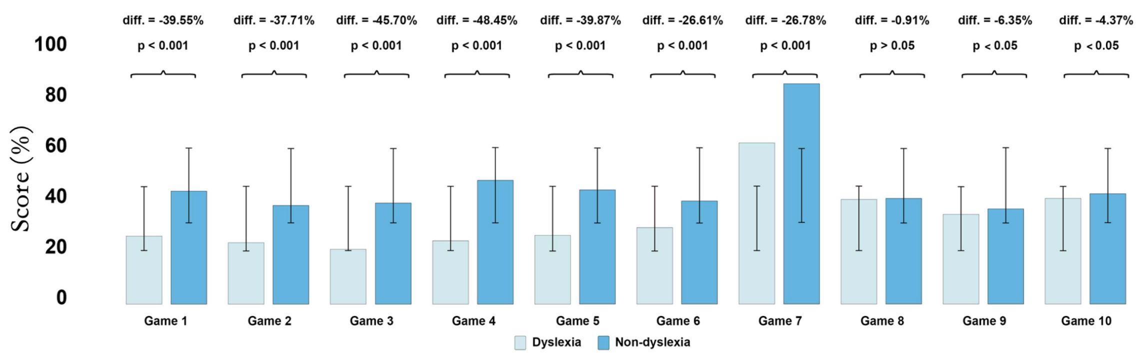

Fig. 13. Score performance of Set 4. Diff. denotes the percentage difference between two groups.

In Set 4 (see Fig. 13), students with dyslexia showed significant weakness in the confusion of word meaning (Game 1), vocabulary size (Game 2), vocabulary expansion (Game 3), odd-man-out (Game 4), and form–sound matching (Game 5), which were 39.55%, 37.71%, 45.70%, 48.45%, and 39.87% lower than those without dyslexia, respectively. These five games are related to MA, VK, and PA. However, the differences were mild in Game 8, corresponding to HW. Overall, the weakness of students with dyslexia covers different linguistic characteristics, as shown in Fig. 9(c).

Overall, the weakness of students with dyslexia covers different linguistic characteristics. As shown in Fig. 9(c), both the groups struggled with HW and VK, which could be attributed to the complexity of the scripts and the students' vocabulary size. However, the disparities between the two groups were more obvious in OA, PA, MA, and VK.

C. Results Regarding Linguistic Characteristics

Table III shows the result regarding linguistic characteristics. The performance of students with dyslexia was far behind those without dyslexia in all the six linguistic characteristics. Except for HW, the differences in other characteristics were statistically significant. Specifically, the differences in MA and VK were the most obvious, and the average scores of students without dyslexia were 41.33% and 38.47% higher than those with dyslexia, respectively. Regarding time consumption, students with dyslexia spent more time on HW and WM than those without dyslexia. The differences were statistically significant. The time consumption differences in HW and WM of students with dyslexia were 40.98% and 24.18% higher than those without dyslexia, respectively.

V. Discussion

The upcoming sections cover several topics, including students' performance in the prescreening tests, their performance in each linguistic characteristic, the potential of gamified environments to motivate students, the significance of the audio recording function, and the challenges encountered while conducting this prescreening test.

A. Performance

In this section, we would like to discuss the linguistic characteristics at which students with dyslexia are weak. Sets 1 and 2 mainly focus on WM and OA. The performance gap between the two groups was relatively small. Sets 3 and 4 are more diverse and cover all the linguistic characteristics listed in Section III-B, and both groups' performance dropped. The performance gap between the two groups was significant, which revealed that students with dyslexia could not master a higher level of Chinese. As shown in Section IV, students with dyslexia could master the fundamental level of Chinese. However, the performance of students with dyslexia declined faster than students without, especially in Sets 3 and 4. Surprisingly, Chinese HW was not very difficult for students with dyslexia, which is different from the observations of previous research [92].

B. Linguistic Characteristics

Although many studies found significant writing difficulties among students with dyslexia [93], [94], our test results revealed that the writing ability gap between the two groups was relatively small. Instead, students with dyslexia showed a larger discrepancy from their peers in other linguistic characteristics, such as WM, OA, PA, and MA. The following section discusses students' performance in each linguistic characteristic.

First, the scores of the linguistic characteristics are quite different between the two groups, except for HW, which is different from prior research [95]. The result revealed that some HW characteristics may exist in English but not Chinese. For example, transposition is a common characteristic in English [96], and students with dyslexia may spell "was" as "saw." However, only rare cases of Chinese characters have transposed forms (e.g., 叻 and 加). Therefore, transposition is not a good matrix for prescreening students with dyslexia in Chinese.

Second, the motor skills of young children may not be well developed, and they may not be able to write words neatly. Most young children may face the same HW problem [97], and HW disability may not be the most significant factor in prescreening students with dyslexia. Also, students with dyslexia constitute a diverse group with varying profiles of strengths and weaknesses. While writing difficulties are commonly associated with dyslexia, the severity and manifestation of these difficulties vary among individuals. Some students with dyslexia may exhibit relatively poor WM abilities compared to their writing skills, leading to a smaller writing ability gap but a larger disparity in WM performance compared to their peers.

Third, the results from both Sets 1 and 2 implied that students with dyslexia performed poorly in WM. WM deficit for students with dyslexia is not limited to phonological component dysfunction but also encompasses visual-object and visual-spatial information [98]. However, students with dyslexia did not exhibit severe difficulties in OA in this study, which differs from previous observations [99]. With sufficient visual hints, students with dyslexia could retrieve their memory.

Fourth, our results revealed that students with dyslexia encountered difficulties with higher levels of tests in Sets 3 and 4 in all the linguistic characteristics, especially VK, MA, and PA. As mentioned above, MA develops the complex relationship between form and meaning [100]. At the same time, VK is measured by how many vocabularies are known and how well the meanings are known. Therefore, the performance of MA can predict the performance of VK.

Finally, after three years of the COVID-19 pandemic, the abilities of both the groups of students may have changed. Before the pandemic, students primarily engaged in F2F instruction, which provided ample time for writing and vocabulary acquisition. However, during the pandemic, students shifted to online learning, reducing writing practice for both the groups of students. As a result, both the groups experienced a decline in their writing abilities. On the other hand, they also had more time to listen, speak, and recognize words during the pandemic. The characteristics of dyslexia may be more evident in areas, such as PA, OA, and MA. Therefore, at-risk students with dyslexia may be identified with different indicators.

C. Time Factor

From the data analysis, the increase in time consumption for both the groups was very similar. Previous research has suggested that students with dyslexia spend more time completing tasks [91], [101]. While our findings are consistent with this, we also found that both the groups, regardless of dyslexia status, required more time to complete difficult tasks, and the percentage of additional time needed was comparable.

The insight gained from this finding is that the task's difficulty level, rather than the presence of dyslexia, is the primary factor in determining the amount of time needed to complete it. This challenges the common assumption that students with dyslexia always require more time to complete tasks and highlights the importance of considering task difficulty when assessing students' performance. In addition, the fact that both the groups required a similar percentage of additional time suggests that accommodations for students with dyslexia such as extra time, may not necessarily put them in an unfair situation compared to their peers.

Furthermore, while some students required more time to complete tasks, they were still able to do so. In such cases, it would be premature to conclude that these students have dyslexia. Instead, they may simply require more time to retrieve knowledge from memory. The longer time required for memory retrieval could be due to various factors such as unfamiliarity with the task type or certain vocabulary [102]. With additional training, students can improve their memory retrieval ability and reduce anxiety [103]. Therefore, we cannot rely solely on completion time to prescreen dyslexia; time can be one of several factors to consider.

D. Gamified Environments and Motivation

The results of this study suggest that most students responded positively to the gamified prescreening tool. In particular, students reported enjoying the games and animations used in the tool. This finding is consistent with previous research by Annetta et al. [104], which found that students often perceive gamified activities as "playing games" rather than "working on a test." The positive response to the animations used in the tool suggests that visual and auditory elements can enhance student engagement in learning activities, which is an important consideration for designers of gamified learning platforms. Interestingly, students were able to recall which game they played, indicating that they could differentiate between the different games presented in the tool. This finding suggests that the gamified prescreening tool effectively engages students and promotes their interest in the learning activities. As noted by Garris et al. [105], the challenge of gamification lies in modifying game features to facilitate instruction by engaging the game cycle that fosters self-directed interest without compromising the enjoyable aspects of games.

E. Strengths of ADPS

The ADPS is a tailored prescreening tool to enhance early identification and intervention. The strengths are threefold. First, the ADPS addresses the unique challenges faced by students with dyslexia in learning Traditional Chinese, filling a gap in the assessment tools. Second, by providing a quick and effective prescreening method, the ADPS can help educators and SENCOs offer timely interventions and support to students at risk of dyslexia, leading to improved academic outcomes and overall well-being. Finally, the gamified design of the ADPS encourages student motivation and self-directed learning, fostering a positive learning environment and reducing the stigma associated with dyslexia assessment.

F. Resolve Resource Scarcity

In Hong Kong, SENCOs have limited resources, and some of them come from non-Chinese backgrounds, which may result in a lack of awareness of reading and writing difficulties in the Chinese language. With this tool, students only need to play four sets of games to help SENCOs understand their performance in different areas of the Chinese language, which speeds up the identification of students at risk of dyslexia.

G. Spotting Chinese Gifted Students With Dyslexia

In addition to identifying students with reading and writing difficulties, this tool can help teachers spot Chinese gifted students with dyslexia. Often, these students have poor grades due to writing difficulties, but they have excellent skills in communication or organization in the Chinese language. With this tool, teachers can provide more appropriate support and assistance, such as providing writing aids or adjusting learning and assessment methods, so that these students can better realize their potential and talents. At the same time, this can help break the stereotype of Chinese gifted students and allow more people to understand their diversity and uniqueness.

H. Limitations

We list several limitations of this study. First, students should sit apart so as not to influence the findings of the prescreening. However, the primary school classrooms in Hong Kong are small, limiting the number of participants. Second, some school infrastructures are insufficient. Due to cloud data uploading and analysis, the prescreening time may increase slightly if the poor Wi-Fi signal quality influences the students' mood. Third, in the reading fluency game, students were suggested to read aloud. However, the students were wearing masks due to the COVID-19 pandemic, making it difficult to collect their voices. Finally, some students told us that the questions from Set 3 were too difficult. The mean score of the experimental group in Set 3 was relatively low, and the scores were most diverse among four sets of prescreening tests ($M = 61.443$ and $\mathrm{SD} = 16.123$). Furthermore, the experimental group spent the longest time in Set 3 (i.e., $M = 839.27$ and $\mathrm{SD} = 220.075$). However, the increase in difficulty levels of the questions is inevitable. We may rearrange the order of the four sets of games and mix questions of different difficulty levels.

VI. Conclusion

This study introduced the ADPS, an efficient prescreening tool for identifying dyslexia in Traditional Chinese. Using six linguistic characteristics for prescreening yielded a more comprehensive assessment than relying on a single characteristic or nonlinguistic-based screening. Furthermore, incorporating user-friendly design elements, such as TTS and touchscreen-enabled user interfaces, engaged students to complete the prescreening independently without encountering technological literacy issues.

The user study showed that students with dyslexia tend to exhibit weaknesses in VK, MA, and OA. Future research should prioritize improving students' linguistic ability and start with VK to establish a solid foundation for students. Moreover, students with dyslexia often struggle with WM. Therefore, early intervention by SENCOs should focus on enhancing WM through visual training [106].

In the future, we will extend the ADPS to a larger audience. In particular, all the games in the ADPS are transferable to other languages, such as Simplified Chinese, Japanese, and Korean, with minor adjustments in the UI design. Furthermore, given that the strengths and weaknesses of students can be identified through the prescreening tool, this work could be extended to a training tool that provides personalized training for students.

Acknowledgment

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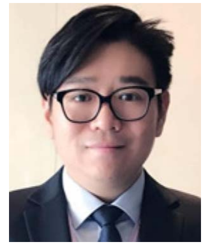

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