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中文字視知覺測驗之發展與心理計量特性驗證

Development and Psychometric Validation of the Chinese Character Visual Perception Test

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中文字視知覺測驗之發展與心理計量特性驗證

Development and Psychometric Validation of the
Chinese Character Visual Perception Test

本論文係蔡艾融（R12429002）於國立臺灣大學職能治療學系所完成之碩士學位論文，於民國114年6月25日經下列考試委員審查通過及口試及格，特此證明。

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摘要

前言：書寫是學齡兒童日常生活中的一項重要任務，而視知覺則是成功完成書寫的基本要件。若視知覺能力不足，可能對書寫表現產生負面影響，進而損害學業成就及心理健康。儘管視知覺的重要性已受到重視，然而，目前的工具仍無法全面且精確地評估中文書寫所需的視知覺能力。因此，本研究旨在開發一個專為評估兒童中文書寫相關視知覺能力的測驗工具。此外，本研究亦檢驗此工具的心理計量特性，包括內部一致性、再測信度、測量誤差及建構效度，以確保其在臨床應用中的可靠性與有效性，進而促進視知覺相關問題的早期診斷與介入。

方法：中文字視知覺測驗（Chinese Characters Visual Perception Test, CCVPT）包含三個分測驗：視覺辨識、視覺空間知覺、視覺記憶。題目設計基於中文字的視覺特徵，包括階層結構與組字原則。為評估該測驗之心理計量特性，本研究招募小一與小二學生共 51 名。其中 20 位學生於兩週內接受再測，以檢驗再測信度與最小可偵測變化值 (minimal detectable change, MDC)；另有 23 位小一學生於六個月後再次接受評估，以探討其對未來書寫表現的預測能力。建構效度藉由測試五個假設進行檢驗。

結果：中文字視知覺測驗在所有分測驗 (Cronbach's α = 0.74–0.80) 及總分 (Cronbach's α = 0.89) 皆展現良好的內在一致性。在低年級學童中，再測信度結果顯示視覺辨識（ICC = 0.62）與視覺記憶（ICC = 0.61）分測驗具中度信度，視覺空間知覺分測驗（ICC = 0.77）與總分（ICC = 0.87）則具良好信度。測量誤差在各分測驗中屬可接受範圍 (MDC_{95}% = 13.43%–16.76%)，而總測驗的測量誤差則達優異水準 (MDC_{95}% = 8.56%)。結果支持中文字視知覺測驗的建構效度，五項預設假設中有四項（80%）被證實。本測驗：(1) 與既有視知覺測驗（視知覺技巧測驗第四

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版）之間具低至中度相關；(2) 與視覺動作整合測驗（拜瑞－布坦尼卡視覺動作整合發展測驗第四版）之間具低至中度相關；(3) 與書寫表現呈現低至中度相關，包括書寫速度（以基本讀寫字測驗抄寫測驗中的字數計算）、正確性（以基本讀寫字測驗抄寫測驗中正確字數的百分比計算）、易讀性（兒童中文書寫易讀性測驗）及家長評估的書寫表現（兒童寫字表現評量表）；以及 (4) 與書寫表現的相關性高於視知覺技巧測驗第四版。然而，對於 (5) 預測書寫表現隨時間變化的能力，支持證據有限。

結論：中文字視知覺測驗融合中文字的視覺特徵，於國小低年級學童中展現良好的信度與效度，顯示其在評估與中文書寫相關之視知覺能力具備潛力。整體而言，本測驗具有良好的臨床應用價值，適用於學齡初期兒童之視知覺功能評估。建議未來研究可進一步探討其於不同年齡層的適用性，以驗證並拓展本研究之發現。

關鍵字：視知覺、中文字、書寫、學齡孩童、信效度

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Abstract

Introduction：Handwriting is an essential occupation for school-aged children, with visual perception playing a crucial role in its successful execution. Deficits in visual perception abilities can negatively impact handwriting proficiency, potentially affecting academic achievements and mental health. Despite the importance, the existing visual perception assessment tools might be insufficient to address the specific demands of Chinese handwriting. Thus, the purpose of this study was to develop a new assessment tool specifically designed to evaluate the visual perception abilities related to Chinese handwriting performance in children. Furthermore, the psychometric properties of the tool, including internal consistency, test-retest reliability, measurement error, and construct validity, were examined to ensure its clinical applicability in facilitating the early diagnosis and intervention of visual perception-related issues.

Methods：The Chinese Characters Visual Perception Test (CCVPT) comprises three subtests: visual identification, visual-spatial perception, visual memory. The items were designed based on the features of Chinese characters, including their hierarchical structures and compositional principles. To evaluate its psychometric properties, 51 first- and second-grade students were recruited. Among them, 20 students were assessed twice within a two-week interval to estimate test-retest reliability and minimal detectable change (MDC). Additionally, 23 first-grade students were reassessed after a six-month interval to investigate its predictability for handwriting performance. Construct validity was examined through testing five hypotheses.

Results：The CCVPT showed good internal consistency across all subtests (Cronbach's $\alpha = 0.74–0.80$) and the total score (Cronbach's $\alpha = 0.89$). The coefficients of test-retest reliability were moderate for visual identification (ICC = 0.62) and memory subtests (ICC = 0.61), and good for visual-spatial perception subtest (ICC = 0.77) and total score (ICC

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= 0.87). Measurement error was acceptable for all subtests (MDC_{95}% = 13.43%–16.76%) and excellent for the total score (MDC_{95}% = 8.56%). Construct validity of the CCVPT was supported, with four out of five (80%) predefined hypotheses confirmed. Specifically, the CCVPT demonstrated: (1) weak to moderate correlations with existing measures of visual perception (Test of Visual Perceptual Skills–4th Edition, TVPS-4); (2) weak to moderate correlations with visual-motor integration (Berry-Buktenica Developmental Test of Visual-Motor Integration–4th Edition); (3) weak to moderate correlations with handwriting performance, including speed (measured by word count in the copy subtest of the Battery of Chinese Basic Literacy, BCBL), accuracy (percentage of correct words in the BCBL), legibility (Chinese Handwriting Legibility Assessment for Children), and parent-reported performance (Chinese Handwriting Evaluation Form); and (4) stronger associations with handwriting performance compared to the TVPS-4. However, limited support was found for the 5th hypothesis regarding the CCVPT's ability to predict handwriting performance over time.

Conclusions： The CCVPT, which incorporates the visual features of Chinese characters, demonstrated good reliability and validity among lower-grade elementary school children. These findings suggest its potential as a tool for assessing children's visual perceptual abilities, particularly in relation to Chinese handwriting performance. The results support the CCVPT's clinical utility and its suitable for evaluating visual perception in early school-aged children. Future studies are recommended to examine its applicability across different age groups to support and extend the current findings.

Keywords: visual perception, Chinese Character, handwriting, school-age children, reliability and validity

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Chapter 1 Introduction

1.1. Importance of Handwriting

Handwriting is a critical occupation for school-age children to successfully participate in school life (Fogel et al., 2022; Grajo et al., 2020; Marquardt et al., 2016). It occupies 30-60% of the day through activities and classwork, including copying from the board to a notebook, writing answers in a book or on paper when doing homework, composing essays, taking tests and more (Barnett et al., 2018; Caramia et al., 2020; Feder & Majnemer, 2007; Hammerschmidt & Sudsawad, 2004; McHale & Cermak, 1992). In Taiwan, approximately 4% to 7% of elementary school children experience difficulties with handwriting (Chang & Yu, 2005; Tseng, 1994). Children with handwriting difficulties often struggle with poor handwriting legibility and efficiency (Chang & Yu, 2005; Tse et al., 2019; Tse et al., 2014; Tseng, 1994). Difficulties in this skill can negatively impact academic achievement, which in turn affects learning experiences, leading to reduced self-competence, self-efficacy, and self-esteem, and ultimately further affecting well-being (Engel-Yeger et al., 2009; Feder & Majnemer, 2007; Grajo et al., 2020; Marquardt et al., 2016).

Handwriting difficulties are frequently linked to underdevelopment or impairment of visual perception, an essential component of the handwriting process (Chang & Yu, 2005, 2017; Cheung, 2007; Feder & Majnemer, 2007; Lee et al., 2016; Poon et al., 2010). Visual perception enables children recognize and process visual information, which forms the foundation for handwriting skills (Feder & Majnemer, 2007; Tse et al., 2019). Additionally, visual perception directly influences each stage of the handwriting process. In the intention stage of writing, the brain processes the visual image of the target. Based on visual perceptual abilities, it identifies the spatial information between letterforms and determines their positions, which forms the basis of the writing plan (Rosenblum et al.,

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2003). The motor plan is then developed, specifying the sequence, direction, and force of each stroke, all of which rely on the precision of visual perception (Palmis et al., 2017; Verma & Lahiri, 2021). During the execution stage, visual perception continues to guide adjustments to the positioning of strokes, ensuring the legibility of the letterforms (Verma & Lahiri, 2021). Deficits or impairments in visual perception can disrupt handwriting process and negatively affect handwriting quality (Case-Smith & O'Brien, 2010; Lee, 2022; Poon et al., 2010; Volman et al., 2006). In summary, visual perception abilities influence the handwriting performance of school-age children, affecting both the intention, execution and overall quality of handwriting.

1.2. Role of Visual Perception in Chinese Handwriting

1.2.1. Definition and Development of Visual Perception

Visual perception refers to the process of organizing and interpreting visual information. Initially, visual input is received by the eyes and converted into electrical signals by the retina. These signals are subsequently processed and interpreted by the brain. This intricate neural circuitry enables us to comprehend visual stimuli (Andrei et al., 2019; Bear et al., 2016; Bütün Ayhan et al., 2015; Goldstein, 2014). Impairment or underdevelopment of visual perception abilities can compromise the accuracy of object recognition and interpretation of visual stimuli (Case-Smith & O'Brien, 2010; Goldstein, 2014).

According to Warren's hierarchical model of visual processing, visual perception develops in a bottom-up manner, with each level of the hierarchy supporting the development of the level above it. It begins with foundational skills such as oculomotor control, visual fields, and visual acuity, and progresses toward more complex abilities like visual attention, scanning, pattern recognition, visual memory, and visual cognition (Schneck, 2005; Warren, 1993). Among these visual perceptual abilities, pattern

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recognition refers to the ability to store a visual image in memory and later recall it, involving the identification of the salient features of an object. This process is closely linked to the ventral stream (the "what" pathway), which is responsible for identifying the object's shape, form, color, and texture. These elements are critical for recognizing objects and distinguishing specific features. Additionally, the dorsal stream (the "where/how" pathway) processes spatial relationships and guides our understanding of an object's position and orientation in space (Goodale & Milner, 1992).

From 3 months of age, infants begin to develop visual attention and visual search abilities as the ventral and dorsal visual pathways become functional. The cortical control of eye and head movements facilitates the integration of eye movements, enabling the infant to associate visual stimuli with occurring events. Between the ages of 2 and 5, children enhance their visual perceptual skills, including categorizing object attributes through visual discrimination and performing simple tasks using visual memory (Zimmermann et al., 2019). During the preschool years, children begin to recognize more abstract language symbols through visual cues, which form the foundation for future handwriting (李宥慧, 2020). As they transition to early grades, visual perceptual skills continue to develop, with significant growth observed by age 9 (王方伶 et al., 2009). At this stage, copying content onto paper becomes a primary handwriting task (Chang & Yu, 2005; Feder & Majnemer, 2007; Tse et al., 2019). Therefore, visual perception should be emphasized and concerned. If children lack adequate visual perception skills, it might affect their handwriting performance and could have broader implications for their academic performance and overall developmental well-being.

1.2.2. Characteristics of Chinese Handwriting

Chinese characters are unique in their visual and structural characteristics, which can be elaborated through three aspects. First, Chinese belongs to logographic system

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composed of square-shaped characters. Each character represents a morpheme or a meaningful unit of language (Chan et al., 2019; Ramoo et al., 2021; 洪儷瑜, 1997). Second, it exhibits a structural hierarchy, where strokes combine to form components, which are subsequently assembled into complete characters (Lau, 2020; 洪儷瑜, 1997; 陳學志 et al., 2011). Third, Chinese characters possess unique compositional structures, which have been categorized into five primary configurations: left-right, top-bottom, P-shaped, L-shaped, and enclosed arrangements (Yeh et al., 1999).

These structural complexities suggest that writing Chinese characters demonstrate greater demands on visual perception compared to alphabetic writing systems like English (Braddick & Atkinson, 2011; Ding et al., 2004; Wang et al., 2018). Specifically, the structural hierarchy and compositional structure of Chinese characters demand precise stroke placement and accurate perception of spatial relationships among strokes and components (Lau, 2020; Lee et al., 2016; 曾美惠, 1993). These characteristics underscore the critical role of visual perception in mastering Chinese handwriting.

1.2.3. Role of Visual Perception in Writing Chinese

Chinese characters are characterized by intricate structural and spatial configurations, requiring distinct visual perceptual skills for effective handwriting. To recognize and write Chinese characters, various visual perception skills are required. In this process, one must identify the features of the characters (visual identification), analyze their spatial properties (visual-spatial perception), and memorize them (visual memory). (Case-Smith & O'Brien, 2015; Chang et al., 2024; Chang & Yu, 2017; Goddard, 2017; Goodale, 2014; Goodale & Milner, 1992; Lee, 2022; Poon et al., 2010; Roussy et al., 2021; 杜婉茹 et al., 2009; 洪儷瑜, 1997). Specifically, visual identification enables individuals to identify and differentiate the features of an object, allowing them to distinguish Chinese characters by their strokes, components, and features. Visual-spatial perception helps

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individuals understand the relative positions and spatial relationships between objects, enabling individuals to analyze the positioning, spacing, and proportions of strokes and components within Chinese characters. Besides, visual memory facilitates the storage and retrieval of perceptual inputs, allowing individuals to recall and process the structure and details of Chinese characters when writing. Together, these three visual perceptual skills provide essential support for Chinese handwriting, particularly in mastering the intricate details and complex structures of characters (Li-Tsang et al., 2023; Li-Tsang et al., 2013; Tse et al., 2019; Wu et al., 2014). The following sections would provide a more detailed exploration of these three concepts.

Visual identification refers to an individual's ability to identify the characteristics of an object, which enables recognition (Eysenck & Keane, 2015; Goodale, 2014; Herath et al., 2001; Treisman, 1988). This ability is particularly useful for identifying Chinese characters, including details of each stroke and component within the characters. It supports distinguishing similar characters and aids reading comprehension (McBride-Chang & Treiman, 2003). Research by Pine et al. (2003) reveals that children focus on visual details such as strokes and components when learning to recognize Chinese characters. This study emphasis on visual identification helps distinguish small structural differences, which is crucial for accurate handwriting (Huang, 1984; Pine et al., 2003). This ability is fundamental for developing both word recognition and handwriting accuracy.

Visual-spatial perception refers to identification of the position of an object and the perception of the relative location of other objects nearby (Goodale, 2014; Wu et al., 2014). Visual-spatial perception could aid in analyzing the structure of Chinese characters, focusing on aspects like spacing and proportions between strokes and components. These aspects are key indicators of handwriting performance (Chang & Yu, 2005;

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Hammerschmidt & Sudsawad, 2004; Marquardt et al., 2016; Tseng, 1994). For example, writing characters like "湃" requires precise judgment of the proportion between its left and right components to ensure structural balance. Cross-cultural research shows that children in China and Korea performed better in visual matching tasks compared to children in Spain and Israel, highlighting how Chinese orthography increase learners' visual-spatial skill (McBride-Chang et al., 2011). Furthermore, Tan et al. (2001) found that the peak brain activation in the left lateral middle frontal cortex, a region that mediates visual-spatial perception, is found in Chinese reading only, indicated that the logographic structure of Chinese characters may demand special visual-spatial processing.

Visual memory refers to the ability to process and recall the visual information necessary for accurately copying Chinese characters, including the structures and finer details (He et al., 2005; McBride-Chang et al., 2011). Each Chinese character demands precise memorization of features of stroke and component, posing significant cognitive challenges. Pelli et al. (2006) found that, compared to Hebrew or Roman alphabets, Chinese characters are processed less efficiently, reflecting their structural complexity. This complexity underscores the need for visual memory in accurately recalling and processing these characters. Research indicates that individuals with experience in Chinese characters exhibit superior visual working memory compared to non-experts, highlighting the role of visual memory in writing proficiency (Zimmer & Fischer, 2020).

In summary, visual perception in Chinese writing involves processing and interpreting the intricate structural details of characters. Writing Chinese characters imposes distinctive demands on visual perceptual abilities, encompassing visual identification, visual-spatial perception, and visual memory. These skills could influence children’s handwriting performance and shape overall literacy development.

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1.2.4. Relationship Between Visual Perception and Chinese Handwriting

Many scholars believe that visual perception would influence handwriting performance; however, studies focusing on Chinese characters have reported inconsistent findings. A literature review reveals inconsistencies in the relationships between visual perception and Chinese handwriting performance in school-aged children, as summarized in Table 1. In those papers, handwriting performance can generally be categorized into three key areas: handwriting accuracy, handwriting legibility, and handwriting speed (Chang & Yu, 2005; Li-Tsang et al., 2013; Tseng, 1994). Handwriting accuracy refers to the production of non-standard or non-existent characters caused by errors such as adding or omitting strokes, reversing orientations, or mirroring characters (Chang & Yu, 2005; Tseng, 1994). Handwriting legibility reflects how easily others can read the written text. Factors such as inappropriate font size, inconsistent positioning, excessive slant, and poor component proportions can negatively affect legibility (Chang & Yu, 2005; Tseng, 1994; 李冠儀 et al., 2021). Handwriting speed refers to the number of words completed within a certain time frame or the time required to complete writing (Tseng & Hsueh, 1997). The following section explores the relationship between visual perception and handwriting performance in school-age children.

First, for visual identification (VI), regarding handwriting accuracy, Li-Tsang et al. (2022), using the Test of Visual Perceptual Skills–3rd Edition (TVPS-3) to assess school-age children, observed a significant correlation between visual identification and handwriting accuracy. However, Hwang et al. (2024), using the same tool to examine predictor of grade 1 handwriting performance, found no such relationship. As for handwriting legibility, Lee (2022), using the Developmental Test of Visual Perception–2nd Edition (DTVP-2) to assess children from grades 1 to 3, reported a significant correlation between visual identification and handwriting legibility. In contrast, Lee et al.

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(2016), employing supplementary tests from the Berry Buktenica Developmental Test of Visual-Motor Integration in school-age children, found no such relationship. Regarding handwriting speed, no studies have found the correlation between visual identification and handwriting speed (Hwang et al., 2024; Li-Tsang et al., 2022; Tse et al., 2014; Tseng & Chow, 2000). These findings highlight variability in the role of visual identification, with evidence supporting its link to handwriting accuracy and legibility in some studies but not universally.

For visual-spatial perception (VS), regarding handwriting accuracy, Hwang et al. (2024), using the TVPS-3 to examine predictor of grade 1 handwriting performance, identified visual-spatial perception as a predictor of handwriting accuracy. However, Li-Tsang et al. (2022), also using the TVPS-3 to assess school-age children, found no such relationship. As for handwriting legibility, Lee (2022), using the DTVP-2 to assess children from grades 1 to 3, and Tse et al. (2014), comparing children with handwriting difficulties to typically developing peers, both reported significant correlations with visual-spatial perception. In contrast, Hwang et al. (2024), using the TVPS-3, observed no such relationship. Regarding handwriting speed, no studies have reported a significant association with visual-spatial perception (Hwang et al., 2024; Li-Tsang et al., 2022; Tse et al., 2014; Tseng & Chow, 2000). These findings indicate that the association between visual spatial perception and handwriting accuracy and legibility remain inconsistent.

Finally, for visual memory (VM), regarding handwriting accuracy, Li-Tsang et al. (2022), using the Test of Visual Perceptual Skill-3 (TVPS-3) to assess school-age children, reported a significant correlation between visual memory and handwriting accuracy. However, Hwang et al. (2024), using the same tool to examine predictor of handwriting performance in early elementary grades, found no such relationship. As for handwriting legibility, no study has reported an association with visual memory (Hwang et al., 2024).

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Regarding handwriting speed, Tseng and Chow (2000), comparing normal and slow-handwriting groups, identified visual memory as a predictor of handwriting speed in the slow-handwriting group, though this finding was not confirmed by other studies (Hwang et al., 2024; Li-Tsang et al., 2022). Overall, findings suggest that the contribution of visual memory to handwriting accuracy and speed remains inconclusive.

In conclusion (Table 1), based on the results of these studies, some discrepancies in the relationship between visual perception abilities and handwriting performance has been observed. Although these studies focused on children of the same age group and used similar or identical tools for measurement, the results showed inconsistent findings. This inconsistency has been suggested by recent scholars to be related to the assessment tools commonly used in studies, such as TVPS, VMI, and DTVP (李佳儒 et al., 2020; 林巾凱 & 曾美惠, 2001), which involve geometric designs that may not fully capture the complexity of Chinese character (Wu et al., 2014; 李宥慧, 2020; 洪儷瑜, 1997; 陳慶順, 2001). As a result, they may not accurately assess the impact of visual perception abilities on Chinese handwriting.

Furthermore, the ceiling effect in visual perception scores has been observed in two studies (Lee et al., 2016; Tseng & Chow, 2000). An cross-cultural research indicates that children learning Chinese demonstrate superior visual perception abilities (McBride-Chang et al., 2011). The study found that Korean and Chinese children outperformed their Spanish and Hebrew peers in visual perception tasks, with Hong Kong children aged seven and above reaching ceiling performance. Similarly, Demetriou et al. (2005) indicated that Chinese individuals excelled in tasks involving processing efficiency, working memory, and reasoning compared to Greeks, attributed to the intensive visual processing demands of Chinese logographic writing system. Ma et al. (2022) further suggests that mastering the complexity of Chinese character enhances higher-level visual

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perception, setting Chinese learners apart from those studying languages like German, which are less visually demanding. However, the norms of commonly used assessment tools are primarily developed for populations who do not use Chinese as their primary language. As a result, native Chinese learners often score higher than average, leading to inaccurate evaluations of their true abilities.

These limitations reduce the applicability of commonly used assessments in evaluating Chinese handwriting, leading to lower interpretability and inconsistent results when predicting handwriting outcomes. Therefore, it is recommended to develop visual perception tests specifically designed for Chinese handwriting to more accurately evaluate the role of visual perception abilities in Chinese handwriting performance.

1.3. Evaluation of Chinese Character Relevant Visual Perception

1.3.1. Existing Assessments

Based on the literature review, there are three currently developed and validated visual perception assessment tools that consider the features of Chinese characters. The previous visual perception test that considering feature of Chinese character are listed in Table 2., including Test of Visual Perception of Chinese Characters (洪儷瑜, 1997), Visual Process Assessment (蔡慧菁, 2005), and Computerized Visual Perception Assessment Tool for Chinese Characters Structures (Wu et al., 2014).

The first assessment that considers the features of Chinese characters is the Test of Visual Perception of Chinese Characters by 洪儷瑜 (1997). The Test of Visual Perception of Chinese Character was designed for second to fifth-grade elementary school students and evaluates visual perception of Chinese characters. It comprises six subtests: memory span, sequential memory, figure discrimination, character discrimination, component discrimination, and awareness of orthography, with a total of 114 items. In the memory span subtest, participants memorize 2 to 5 Greek characters and identify them among

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distractors. The sequential memory subtest involves recalling 3 to 4 characters in the correct order. The figure discrimination subtest tests recognition of geometric figure combinations. The character discrimination subtest uses pseudo-characters to assess recognition. Component discrimination requires identifying a pseudo-character missing a common component. Finally, awareness of orthography asks participants to identify a character that doesn't conform to Chinese character rules. The Test of Visual Perception of Chinese Character demonstrates acceptable concurrent, and construct validity. Additionally, its internal consistency (Cronbach's α) and test-retest reliability (r) have been examined. However, this assessment tool does not measure visual-spatial perception and does not adequately consider the structural complexities of Chinese characters, such as strokes, components, and compositional principles. As a result, it does not fully reflect the complexity of Chinese orthography.

The second tool is the Visual Process Assessment by 蔡慧菁 (2005), developed for first-grade elementary school students. It consists of two subtests: visual memory and visual discrimination. The visual memory subtest uses geometric shapes as stimuli, requiring participants to memorize 12 shapes within 1.5 minutes and select these shapes from 20 shapes. The visual discrimination subtest uses pseudo-characters, comprising 26 items where participants must select the option matching the given stimulus. Norms for the assessment was established based on a sample of 284 elementary school students. Acceptable internal consistency (Cronbach's α), split-half reliability (PCC), and construct validity have been demonstrated. However, this tool does not measure visual-spatial perception and lacks sufficient consideration of the structural complexities of Chinese characters, such as strokes, components, and compositional principles. Therefore, it does not provide a comprehensive understanding of Chinese orthography.

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The third tool is the Computerized Visual Perception Assessment Tool for Chinese Characters Structures by Wu et al. (2014), designed for preschool children aged 4 to 6 years and based on the components and structures of Chinese characters. This assessment includes three subtests: basic strokes, single-component characters, and compound characters, with a total of 58 items. In the basic stroke’s subtest, participants are asked to select the option identical to the target stimulus. In the single-component and compound characters subtests, participants are required to select geometric shapes that align with the spatial structure of the characters. The test demonstrated acceptable internal consistency reliability. For validity, the tool showed good model fit, as indicated by the deviance information criterion (DIC) values. However, this tool does not measure visual memory and does not fully consider the complexity of Chinese orthography. While the assessment includes the compositional principles of characters, it does not address the components, leaving out a critical aspect of structural complexity.

1.3.2. Insufficient of the Existing Assessments

Existing visual perception assessments that consider the features of Chinese characters exhibit two main limitations. First, Chinese handwriting relies on visual identification, visual-spatial perception, and visual memory, which are dimensions that current tools fail to comprehensively address. The Test of Visual Perception of Chinese Characters evaluates visual memory and visual identification but provides insufficient measures for spatial concepts (洪儷瑜, 1997). Similarly, the Visual Process Assessment lacks an evaluation of spatial perception (蔡慧菁, 2005). The Computerized Visual Perception Assessment Tool omits the critical factor of visual memory essential for handwriting proficiency (Wu et al., 2014). This limitation reduces their effectiveness in offering a holistic evaluation.

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Second, the structural complexities of Chinese characters, including hierarchical structures and compositional principles, are insufficiently addressed in existing assessments. The Test of Visual Perception of Chinese Characters does not adequately address the hierarchical structures or consider the compositional principles of Chinese characters. Additionally, the use of Greek characters in the visual memory subtests limits its relevance and overlooks the complexities in Chinese characters (洪儷瑜, 1997). The Visual Process Assessment overlooks the hierarchical structure of components and strokes, as well as compositional principles, which might fail to fully capture their complexity (蔡慧菁, 2005). Although the Computerized Visual Perception Assessment Tool uses strokes and characters and considers compositional principles, it does not consider components, so it fails to address structural nuances comprehensively (Wu et al., 2014). This limitation reduces their ability to fully capture the unique demands of Chinese orthography.

In conclusion, while these tools incorporate certain features of Chinese characters, none provide a comprehensive assessment of the critical visual perception domains required for Chinese handwriting. Additionally, the stimuli used in these assessments do not adequately reflect the hierarchical and structural characteristics of Chinese characters, Future tool development aimed at addressing these limitations could significantly improve the accuracy and applicability of visual perception assessments. By integrating hierarchical and structural aspects of Chinese characters, the tools could provide a more comprehensive evaluation of handwriting challenges, enabling detailed analysis and paving the way for more targeted and effective interventions.

1.4. Research Purpose

Visual perception constitutes a foundational skill critical to the handwriting process. A comprehensive assessment specifically tailored to the visual perceptual demands of

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Chinese characters can facilitate the identification of deficits in visual perception and support the early diagnosis of handwriting difficulties. Early detection of children’s visual perceptual abilities could provide timely and targeted interventions, thereby alleviating challenges associated with handwriting and minimizing the broader impacts of impaired handwriting performance among children learning Chinese. This study aims to: (1) develop an assessment tool designed to systematically evaluate the visual perceptual abilities related to writing in children; (2) investigate the psychometric properties of the tool, including internal consistency, test-retest reliability, minimal detectable change, and construct validity. These evaluations would ensure the tool's clinical applicability in facilitating early diagnosis and intervention for visual perception-related challenges.

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Chapter 2 Methodology

2.1. Development of the Chinese Characters Visual Perception Test

2.1.1. Item Development, Implement and Scoring

Item development was conducted in two phases to ensure that the Chinese Character Visual Perception Test (CCVPT) items accurately measured key visual perception constructs: visual identification, visual-spatial perception, and visual memory. In the first phase, a focus group consisting of ten experts from the pediatric field (three with over five years of clinical experience) worked together to clarify and define the core components of visual perception closely related to Chinese character. Their input provided valuable insights into both theoretical and practical aspects. This process refined the conceptual foundation and provided clear guidance for item development.

The illustration and structure of the test were listed in Table 3. Test items were structured based on the five types of Chinese character, including left-right horizontal structure, top-bottom vertical structure, P-shaped structure, L-shaped structure, and enclosed structure (Yeh et al., 2003; Yeh et al., 1999; Yeh et al., 1997). The CCVPT includes two levels of difficulty across its three subtests. For the visual identification and visual-spatial perception subtests, difficulty was manipulated by the similarity of the distractors. At the easier level, participants were asked to identify the correct answer from four options with fewer distracting elements. At the more difficult level, the distractors closely resembled the target, requiring more advanced visual perceptual discrimination. For the visual memory subtest, difficulty was determined by the memory load. At the easier level, children were asked to remember one Chinese character, while at the more challenging level, they needed to remember two characters, increasing the cognitive demand. Each subtest included four types of items: geometric figures, strokes, components, and Chinese characters. The geometric figures are designed based on 29

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spatial arrangements (Yeh et al., 1999) and are presented in a square form. The strokes are designed using the 28 basic strokes prescribed by the Ministry of Education (National Languages Committee, 1994). The components are based on 273 out of 419 independent elements, which meet the consistency standard of over 70% in component positional regularity (Tseng et al., 2018). The Chinese characters used in the visual-spatial perception and visual memory subtests are selected from a pool of 18,319 rare Chinese characters, adhering to the standards set by the National Languages Committee (2004). This selection aims to challenge participants' recognition and memory of less frequently encountered characters. Furthermore, the visual identification subtest focuses on the ability to recognize fine visual details between similar characters. Difficulty is primarily controlled by the degree of visual similarity among distractors, reducing the impact of character familiarity on responses. Therefore, commonly used characters are incorporated based on the character selection results from Taiwan's 108 Curriculum Guidelines.

In the second phase, an initial pool of 110 items was developed based on the structure and content designed in the first phase. Each item was reviewed individually by the experts to assess its clarity, relevance, and representativeness of the targeted domains. Items that did not meet predefined criteria were revised or removed. Through this item-by-item review process, a finalized set of items was established.

2.1.1.1. Visual Identification

The visual identification subtest is designed to evaluate children’s ability to recognize specific visual features from a surrounding background and identify these features across varying scales. The item selection method for test materials aligns with that of previous subtests. However, the options for the items that belong to strokes and components are based on commonly used characters according to the 108 Curriculum Guidelines in Taiwan. This subtest includes two difficulty levels. In the simple tasks,

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options contain fewer than 10 strokes and include only one distractor (similar feature), whereas in the more challenging tasks, options have more than 10 strokes and include two distractors.

After consulting with occupational therapists, we refined all 30 test items and 90 incorrect options, with experts reviewing each item's design to ensure it aligns with visual identification requirements. During the test, participants view a stimulus on the screen and then select from 4 options the one containing a pattern proportionate to the stimulus. Scoring awards 1 point for each correct response, while incorrect answers receive 0 points. Item examples were list as the followings.

2.1.1.2. Visual-Spatial Perception

The visual-spatial perception subtest aims to evaluate children's ability to distinguish the spatial differences in the composition of the displayed feature, including the size, width, length, and spatial distribution between components. The item selection method for test materials aligns with that of previous subtests. The test is organized into two levels of difficulty. In simple tasks, the two distractor options involve alterations to the entire figure, while in more challenging tasks, each distractor option modifies only one component.

After consultations with occupational therapists, we refined 40 test items and 120 distractor options, ensuring that experts reviewed the design of each item for its relevance to visual-spatial perception. During the testing process, participants should select the option that matches the stimulus item displayed on the screen from 4 options. Scoring awards 1 point for each correct response, while incorrect answers receive 0 points. Item examples were list as the followings.

2.1.1.3. Visual Memory

The visual memory subtest aims to assess children's ability to memorize a feature

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and recognize it after briefly viewing it. The items are categorized across four groups, focusing on five types of structural composition, with one of the categories specifically involving rare Chinese characters. The subtest has two difficulty levels. In the simpler tasks, where participants remember a single stimulus, and more challenging tasks, where they must recall two. Rare characters were included as one of the item categories to address potential influences of word frequency on recognition. Prior research has demonstrated that the familiarity of Chinese characters significantly impacts processing speed and cognitive load during recognition (Kuo et al., 2003; Liu & Perfetti, 2003; Shen et al., 2018). Familiar characters enable faster recognition, shorter response times, and better working memory performance. To mitigate these effects and ensure the assessment focuses purely on visual memory, rare characters were selected as stimuli.

After consulting with occupational therapists, we refined the test items and incorrect options to enhance their alignment with visual memory requirements, ensuring each item's relevance through expert review. The subtest consists of 40 test items and 120 incorrect options. During the test, participants view a stimulus image for 5 seconds before selecting the correct answer from four choices. Scoring awards 1 point for each correct response, while incorrect answers receive 0 points.

2.1.2. Testing Equipment

The assessment takes place in a quiet room, ensuring adequate lighting and a comfortable temperature. Children are seated in height-adjustable chairs, positioned so that their hips and knees are bent at 90 degrees, with their feet flat on the floor and their arms resting on a height-adjustable table, also bent at 90 degrees at the elbows. The equipment includes a tablet computer with a touch screen, and the test is administered using the PsychoPy program. Participants interact with the program by touching the screen and selecting options to proceed to the next question. Before each subtest,

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participants familiarize themselves with the tablet and the question format through a practice trial. Breaks are provided as necessary during the test. The overall duration of the assessment is approximately 30 minutes.

2.2. Psychometric Study of the Chinese Characters Visual Perception Test

2.2.1. Participants

The study adopted a convenience sampling method to recruit 50 lower-grade children. The sample size of participants was estimated according to COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) guidelines (Mokkink et al., 2016; Lidwine B. Mokkink et al., 2010; Prinsen et al., 2018). The inclusion criteria for participation were: (1) currently entering or enrolled in lower grades of elementary school; (2) the ability to write without muscular, skeletal, or sensory limitations; (3) normal Intelligence (measured by the Raven's Colored Progressive Matrices (RCPM) with a standard score > 70) and the ability to comprehend instructions, and (4) normal or corrected-to-normal vision. Informed consent has been obtained from the parents, and the study has been approved by the Institutional Review Board of National Taiwan University Hospital.

2.2.2. Procedure

Psychometric properties of the assessment were examined following the COSMIN guidelines. Regarding reliability, internal consistency, test-retest reliability, and measurement error were evaluated. For validity, construct validity was examined. A total of 50 first- and second-grade students participated in the study to evaluate reliability and validity. Among them, 25 students were randomly invited to assess twice within a two-week interval to estimate test-retest reliability and measurement error. Additionally, 25 first-grade students were invited to reassess over a six-month interval to evaluate construct validity, addressing the concept of predictive validities.

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To ensure consistency and data reliability, all assessments were administered by the same two well-trained occupational therapists across each time point. Testing environments were standardized, with adequate lighting and a comfortable room temperature. The administration of the CCVPT took approximately 30 minutes per session. In addition to the CCVPT, participants completed the Test of Visual Perceptual Skills–4th edition (TVPS-4), the copy subtest of the Beery-Buktenica Developmental Test of Visual-Motor Integration–4th edition (Beery VMI-4), and three handwriting performance assessments: the Battery of Chinese of Pupils (BCBL), the Chinese Handwriting Legibility Assessment for Children (CHLAC), and the Chinese Handwriting Evaluation Form (CHEF). Completion of all assessments required approximately 2 to 2.5 hours. A retest session of the CCVPT was conducted within a two-week interval and lasted about 30 minutes. Additionally, the six-month follow-up session lasted approximately 1 hour and included only the handwriting performance assessments.

2.2.2.1. Internal Consistency Reliability

Internal consistency reflects the degree to which the items within a test measured different aspects of the same underlying characteristic or construct. To establish the internal consistency reliability of the test, all participants completed a single session of the CCVPT. The testing time was approximately 30 minutes.

2.2.2.2. Test-Retest Reliability

Test-retest reliability assesses the extent to which a test consistently produces similar results when administered at different times. To evaluate the test-retest reliability, 20 participants completed a second session of the CCVPT two weeks after the initial session. The testing time was approximately 30 minutes of each section.

2.2.2.3. Measurement Error

Minimal detectable change (MDC) was calculated using the standard error of

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measurement (SEM) to determine the smallest change that can be detected beyond measurement error in test-retest measures (Haley & Fragala-Pinkham, 2006; Schreuders et al., 2003). To evaluate the MDC, 20 participants completed a second session of the CCVPT two weeks after the initial session. The testing time was approximately 30 minutes of each section.

2.2.2.4. Construct Validity

Construct validity was assessed by examining the correlation between different methods used to measure the same psychological construct, ensuring that the tests evaluate the same concept (Lidwine B. Mokkink et al., 2010). To establish the construct validity of the CCVPT, hypothesis testing guidelines based on COSMIN were used. The following hypotheses were proposed:

(1) There are at least a weak to moderate significant positive correlations between CCVPT scores and the TVPS-4. This is because both CCVPT and TVPS-4 measure visual perception; however, the CCVPT incorporates visual perception elements specific to Chinese characters (洪儷瑜, 1997).

(2) There are at least weak to moderate significant positive correlations between CCVPT and the copy subtest of Beery VMI-4. This is because Beery VMI-4 evaluate skills related to visual-motor integration; therefore, the visual perception measured by the CCVPT should correlate with visual-motor integration skills (Fang et al., 2017).

(3) There are at least weak to moderate significant positive correlations between the CCVPT and at least 75% (3 out of 4) Chinese handwriting performance (handwriting speed, accuracy, legibility, and parent-reported handwriting performance). This is because the visual perception measured by the CCVPT should be related to various aspects of handwriting performance.

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(4) The CCVPT shows stronger correlations than the TVPS-4 with at least 75% (3 out of 4) handwriting performances (handwriting speed, accuracy, legibility, and parent-reported handwriting performance). This is because handwriting performance is more closely aligned with the specific visual perception components related to Chinese characters that are assessed by the CCVPT.

(5) The CCVPT performance shows stronger correlations than the TVPS-4 with at least 75% (3 out of 4) handwriting performances (handwriting speed, accuracy, legibility, and parent-reported handwriting performance) after six months of formal handwriting instruction. This is because visual perception abilities, as measured by CCVPT, are foundational for developing effective handwriting skills during formal education (Lee et al., 2016; Li-Tsang et al., 2022; Shen et al., 2012).

2.2.3. Measurements

2.2.3.1. Raven's Colored Progressive Matrices (RCPM)

RCPM is a version of the Raven's Progressive Matrices designed for children aged 6 to 8 years old. It aims to assess general cognitive ability through reasoning about relationships between pieces of evidence, without relying on language or formal education (Raven, 1995). The RCPM consists of 36 items, each requiring the participant to choose one correct figure from six options to complete the missing part. Completing the task takes approximately 20 minutes. In terms of psychometric properties, the RCPM has demonstrated good to excellent internal consistency reliability (Cronbach's $\alpha = 0.86-0.92$) and acceptable test-retest reliability ($r = 0.73$), with criterion-related validity supported by its correlation with academic performance (陳榮華 & 陳心怡, 2006).

2.2.3.2. Test of Visual Perceptual Skills－4th ed. (TVPS-4)

TVPS-4 assesses visual perception in individuals aged 5 to 21 years (Martin, 2017).

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It consists of seven subtests: visual discrimination, visual memory, spatial relationships, form constancy, sequential memory, visual figure-ground, and visual closure. Each subtest contains 18 items, and scoring is based on the number of correct answers. The test terminates scoring if the participant receives zero points on five out of seven items. The TVPS-4 can be completed in approximately 25 minutes. The psychometric properties of the TVPS-4 demonstrate acceptable internal consistency for individual subtests (Cronbach's α = 0.68－0.81), and excellent internal consistency for the overall score (Cronbach's α = 0.94). The test-retest reliability over a two- to three-week interval demonstrated moderate to high levels of consistency (r = 0.46－0.81), while the overall score demonstrated excellent reliability (r = 0.97). The TVPS-4 has also shown good content and construct validity. It also exhibits good criterion validity, with strong correlations to the Motor-Free Visual Perception Test, 4th Edition (MVPT-4) (r = 0.90, $p < 0.001$) (Martin, 2017).

2.2.3.3. Beery-Buktenica Developmental Test of Visual-Motor Integration－4th ed. (VMI-4)

Beery VMI-4 is a standardized, norm-referenced assessment. The Chinese version of VMI and its Supplemental Developmental Tests of Visual Perception (VP) and Motor Coordination (MC) assess visual–motor integration, visual perception, and eye–hand coordination in individuals aged 3 to adulthood (Beery, 1997; Liu, 1999). The VMI consists of 27 geometric forms arranged in a developmental sequence, increasing in complexity. Participants were asked to copy these forms, and scores were used to represent visual–motor integration skills. The administration of the Beery VMI takes approximately 10 minutes to complete. The Beery VMI-4 demonstrates strong psychometric properties. Interrater reliability for visual–motor integration is high (r = 0.96), and test–retest reliability over a two-month interval is also strong (r = 0.91).

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Construct validity is supported by a significant correlation between age and visual–motor integration scores (r = 0.86) (Liu, 1999).

2.2.3.4. Battery of the Chinese of Pupils (BCBL)

BCBL is a standardized test designed to evaluate Chinese reading and writing skills among first to third grade students and school-age children with handwriting difficulties. In this study, only the copying subtests were used to measure handwriting speed and accuracy. Participants were asked to copy 25 characters from an exam sheet (near-copy subtest) and 25 characters presented on a cloth strip (far-copy subtest). Within a two-minute period, the number of copied characters was recorded to assess handwriting speed, and the percentage of correct characters was calculated to evaluate handwriting accuracy. The BCBL demonstrates strong psychometric properties, with an internal consistency (Cronbach's α) of 0.87 and a test-retest reliability of 0.83 for the far-copy subtest. The validity of the test is supported by examining score differences among children across different grades (洪儷瑜 et al., 2003).

2.2.3.5. Chinese Handwriting Legibility Assessment for Children (CHLAC)

CHLAC is designed to evaluate the legibility of Chinese handwriting at the intra-character level for first- and second-grade students. Participants were instructed to replicate each Chinese character within a 2 cm × 2 cm square frame on provided examination sheets. The 10 characters used in this assessment are selected from three major lower-grade textbook series and represent five structural types: horizontal (的，到), vertical (花，要), P-shaped (有，原), L-shaped (這，起), and enclosed (雨，開). The assessment focuses on five domains of legibility: size (overall character dimensions), position (placement of the character in the frame), orientation (character slope), component proportion (relative sizes of components within the character), and component space (spatial relationships between components). The size and position reflect the overall

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legibility of the character, while orientation, component proportion, and component space evaluate the legibility of its internal components. Besides, an additional domain, stroke, gives supplementary information of handwriting legibility. Each character is scored as either correct (1 point) or incorrect (0 point) for each domain. Completing the CHLAC takes approximately 10 minutes. A legibility score below the 25th percentile was used to identify children at high risk for handwriting difficulties. CHLAC demonstrates robust psychometric properties, including excellent intra-rater reliability (r = 0.90–0.99), good to excellent inter-rater reliability (r = 0.82–0.95), and acceptable test-retest reliability (r = 0.52–0.83). Its validity has been well-supported through content validity, criterion-related validity (correlation with the CHEF), and discriminative validity for identifying children with handwriting difficulties (王姝婷 et al., 2024).

2.2.3.6. Chinese Handwriting Evaluation Form (CHEF)

CHEF is a questionnaire designed for parents or teachers to evaluate handwriting performance in preschool and school-aged children, serving as a screening tool for handwriting difficulties and providing tailored intervention recommendations (張韶霞 & 余南瑩, 2012). The preschool version includes 22 items across four dimensions (legibility, functionality, ergonomics, and handwriting behaviors), while the school-aged version has 25 items spanning five dimensions (legibility, accuracy, speed, ergonomics, and directionality). Both versions use 5-point Likert scales to evaluate handwriting performance, with higher scores indicating greater difficulties. The school-aged version also classifies handwriting issues into five subtypes, offering targeted insights for intervention. The school-aged version further classifies handwriting difficulties into five subtypes, providing targeted insights for intervention. The CHEF questionnaire takes approximately 15 minutes to complete. Psychometric analyses reveal strong reliability and validity, with internal consistency ranging from 0.697 to 0.954 for the school-aged

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version and from 0.811 to 0.954 for the preschool version. Significant correlations with related assessments, such as the Basic Literacy and Writing Test and the Movement Assessment Battery for Children (MABC), further support CHEF's effectiveness and applicability for both age groups.

2.2.4. Data Analysis

2.2.4.1. Demographic Information

Demographic information was presented using descriptive statistics. Gender, age, dominant hand, and RCPM scores were reported. Continuous variables were presented as means and standard deviations, while categorical variables were presented as frequencies and percentages.

2.2.4.2. Internal Consistency Reliability

To evaluate the internal consistency reliability of the three subtests and overall test of CCVPT, Cronbach's α was utilized. Cronbach's α (Cronbach, 1951) ranges from 0 to 1, with higher values indicating greater internal consistency; values between 0.7 and 0.9 are generally considered to indicate good reliability, and above 0.9 considered to be excellent (Aaronson et al., 2002).

2.2.4.3. Test-retest Reliability

To evaluate the test-retest reliability of the CCVPT over a two-week interval, the intraclass correlation coefficient (ICC [3,1]) was calculated based on a two-way mixed-effects model with absolute agreement and single measurement (Koo & Li, 2016). This model was chosen because the testing sessions were fixed and the focus was on the absolute agreement of individual scores across time. The ICC ranges from 0 to 1, with higher values indicating greater reliability. An ICC between 0.90 and 1.0 indicates excellent reliability; between 0.75 and 0.90 indicates good reliability; between 0.50 and

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0.75 indicates moderate reliability; below 0.50 indicates poor reliability (Koo & Li, 2016; Shrout & Fleiss, 1979).

2.2.4.4. Measurement Error

The standard error of measurement (SEM) was calculated as $\mathrm{SEM} = \mathrm{SD} \times \sqrt{1 - \mathrm{ICC}}$, where SD is the standard deviation of the pooled sample and ICC is the intraclass correlation coefficient. Based on the SEM, the minimal detectable change (MDC) at the 95% confidence level was computed using the formula $\mathrm{MDC} = 1.96 \times \sqrt{2} \times \mathrm{SEM}$ (Huang et al., 2011). To improve interpretability across scales, the MDC was also expressed as a percentage of the total score (MDC%). An MDC% below 30 is considered acceptable, and below 10 is considered excellent (Huang et al., 2017; Smidt et al., 2002).

2.2.4.5. Construct Validity

The strength of relationships between CCVPT scores and other measures was analyzed using Pearson's correlation coefficient (r). The coefficients range from -1 to 1, and if negative, it indicates that one variable decreases as the other increases; if positive, it indicates that one variable increases as the other increases. A correlation coefficient between 0.70 and 1.0 indicates a strong relationship; between 0.40 and 0.69 indicates a moderate relationship; and between 0.10 and 0.39 indicates a weak relationship (Akoglu, 2018). In comparing the correlation, the Bootstrap method was used to compute 95% confidence intervals for the difference between the correlation coefficients (Efron & Tibshirani, 1994).

Construct validity for the CCVPT was evaluated based on the total number of confirmed hypotheses. It was rated as good if beyond 75% of the hypotheses were confirmed (4 to 5 out of 5), moderate if 50% to 74% were confirmed (3 to 4 out of 5), and poor less than 50% were confirmed (0 to 2 out of 5) (L. B. Mokkink et al., 2010).

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Chapter 3 Results

3.1 Development of the Chinese Character Visual Perception Test

A total of five focus group meetings were held during the development of the Chinese Character Visual Perception Test (CCVPT), and all meetings were documented. In the first meeting, the conceptual framework and operational definitions of each subtest were discussed and finalized. In the second meeting, the item instructions were confirmed, and non-character stimuli were replaced with rare but structurally valid Chinese characters in visual-spatial perception and visual memory subtest as recommended by the experts. In the third meeting, all 110 items were reviewed one by one. During this process, five items were identified as unclear, and these items were revised based on expert suggestions. In the fourth meeting, items that were considered too easy or too difficult were further reviewed and modified to ensure appropriate difficulty levels. Finally, in the fifth meeting, the final version of the test was confirmed, with all items evaluated as appropriate and aligned with the intended constructs.

3.2 Psychometric Study of the Chinese Characters Visual Perception Test

3.2.1 Demographic Characteristics of the Participants

Table 4 presents the demographic characteristics of the participants. There are twenty-six first-grade children (mean age = 6.44 years, SD = 0.31; 17 males, 9 females) and twenty-five second-grade students (mean age = 7.52 years, SD = 0.34; 16 males, 9 females) were included in this study. All participants demonstrated normal intelligence (mean score of RCPM = 105.24, SD = 13.00) and none of them reported uncorrected visual impairments. Informed consent was obtained from the parents and from children aged seven and above. Except for one second-grade student who did not complete the Beery VMI-4, all participants completed the full set of assessments. The results of their scores are presented in Table 5.

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3.2.2 Internal Consistency Reliability

All 51 participants were included in the evaluation of internal consistency. The CCVPT demonstrated good internal consistency, with Cronbach's α coefficients of 0.71 for visual identification, 0.80 for visual-spatial perception, 0.74 for visual memory, and 0.89 for the total score. To ensure rigorous validation, Cronbach's α coefficients were calculated separately for first- and second-grade students. The results indicated comparable internal consistency across both grade levels. Based on the criterion that values above 0.70 are generally considered acceptable, these findings indicate that the CCVPT demonstrates acceptable to excellent internal consistency across subtests, and excellent consistency for the total score. The results of internal consistency are presented in Table 6.

3.2.3 Test-retest Reliability

20 children (mean age = 7.16 years, SD = 0.66; 12 males and 8 females) were asked to complete the CCVPT again within a two-week interval. The demographic characteristics of these children are presented in Table 7. The CCVPT scores from the first and second administrations are presented in Table 8.

The results demonstrated that the intraclass correlation coefficients (ICCs) were 0.62 for visual identification ($p < .01$), 0.77 for visual-spatial perception ($p < .001$), 0.61 for visual memory ($p < .01$), and 0.87 for the total score ($p < .001$). Additionally, Pearson's correlation coefficients (r) showed significant moderate to high correlations between the first and second test administrations. Specifically, visual identification showed a correlation of $r = 0.66$ ($p < .01$), visual–spatial perception $r = 0.78$ ($p < .001$), and visual memory $r = 0.61$ ($p < .01$). The total score demonstrated a strong correlation of $r = 0.89$ ($p < .001$). Based on the criteria that ICC values above 0.50 indicate moderate reliability, values above 0.75 indicate good reliability, and values above 0.90 indicate excellent

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reliability, the CCVPT demonstrated moderate to good test–retest reliability across subtests and good reliability for the total score. The results of test-retest reliability are presented in Table 9.

3.2.4 Measurement Error

The standard error of measurement (SEM) was calculated using the pooled standard deviations of each subtest and total scores across both time points, along with the corresponding ICCs. The minimal detectable change (MDC) was then calculated based on the SEM. The results demonstrated acceptable levels of measurement error, with MDC% values of 14.48% for visual identification, 16.76% for visual-spatial perception, 13.43% for visual memory, and 8.56% for the total score. Based on the criterion that MDC% values below 30% are considered acceptable and values below 10% are considered excellent, the results indicate that the CCVPT demonstrates acceptable measurement error across all subtests and excellent for the total score. The results of measurement error are presented in Table 9.

3.2.5 Construct Validity

Hypothesis testing was conducted to establish the construct validity of the CCVPT. Data from 51 children who completed all assessments were used to test hypotheses 1st to 4th, while data from 23 children who completed the assessment after six months were used to test hypothesis 5th. Details corresponding to each hypothesis are presented below.

(1) We hypothesized that there would be at least weak to moderate correlations between CCVPT scores and the TVPS-4. The result presented in Table 10 supported this hypothesis, as the standard total scores of the TVPS-4 showed significant moderate correlations with all subtests and the total score of the CCVPT (r = 0.45–0.65, *p*s < .05).

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(2) We hypothesized that there would be at least weak to moderate correlations between CCVPT scores and the copy subtest of Beery VMI-4. The result presented in Table 10 supported this hypothesis, as the standard scores of the VMI demonstrated significant moderate correlations with all subtests and the total score of the CCVPT (r = 0.45–0.53, *p*s < .05).

(3) We hypothesized that there would be at least weak to moderate correlations between the CCVPT and the Chinese handwriting performance, including handwriting speed, accuracy, legibility, and parent-reported handwriting performance. The results presented in Table 11 supported this hypothesis, with 75% (3 out of 4) domains of handwriting performance demonstrated significant correlation with the CCVPT. The correlations for each domain of handwriting performance are presented as follows:

Handwriting speed, the number of words copied in two minutes, showed no significant correlation with the total CCVPT score. However, among the subtests, visual memory demonstrated weak to moderate significant correlations with handwriting speed (near: r = 0.38, *p* = .006; far: r = 0.35, *p* = .013; total: r = 0.38, *p* = .007), while visual identification and visual–spatial perception showed no significant associations with speed. Handwriting accuracy, the percentage of correct characters copied in two minutes, was significantly correlated with the total score of CCVPT (near: r = 0.49, *p* < .001; far: r = 0.44, *p* = .001; total: r = 0.54, *p* < .001). All three subtests also showed weak to moderate correlations with accuracy (near: r = 0.35–0.49; far: r = 0.32–0.43; total: r = 0.43–0.54; *p*s < .05). Handwriting legibility, as measured by CHLAC, was weakly to moderately correlated with the total CCVPT score (r = 0.63, *p* < .001) and with each subtest (visual identification r = 0.50, visual-spatial perception r = 0.58, and visual memory r = 0.54, *p*s < .001). Parent-report

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evaluation, as measured by CHEF, showed a weak but significant correlation with the total score of the CCVPT (r = 0.29, *p* = .039) and the visual memory subtest (r = 0.37, *p* = .008). In contrast, no significant correlations were found with the visual identification and visual-spatial perception subtests.

(4) We hypothesized that there would be a stronger correlation between CCVPT and the handwriting performance, such as handwriting speed, accuracy, and legibility, than with the TVPS-4. To examine this, bias-corrected and accelerated (BCa) bootstrap confidence intervals (based on 1,000 iterations) were computed to compare the strength of the correlations. As summarized in Table 12, the results generally supported our hypothesis, with 100% (4 out of 4) domains of handwriting performance showing stronger correlations with the CCVPT under bootstrap analysis. In addition, Pearson's correlation coefficients were calculated and display in Table 12 to provide supplementary information regarding the significance of the associations between handwriting performance and the two visual perception assessments.

For handwriting speed, the CCVPT showed a stronger association (difference = 0.47, 95% CI = 0.25 to 0.71), as well as for handwriting accuracy (difference = 0.52, 95% CI = 0.31 to 0.74) and handwriting legibility (difference = 0.48, 95% CI = 0.26 to 0.70). Specifically, within legibility subdomains, the CCVPT was more strongly correlated than the TVPS-4 with both the character domain (difference = 0.31, 95% CI = 0.12 to 0.56) and the component domain (difference = 0.49, 95% CI = 0.29 to 0.72). Additionally, the CCVPT demonstrated a significantly stronger correlation with the percentile rank from the CHEF (difference = 0.24, 95% CI = 0.05 to 0.53).

(5) We hypothesized that first-grade children's performance on the CCVPT would show stronger correlations with handwriting performance after six months of formal handwriting instruction compared to the TVPS-4. The demographic characteristic of

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the 23 participants who completed both the handwriting performance assessment and the CCVPT after one semester are presented in Table 13. Table 14 presents the descriptive statistics of CCVPT scores across two time points.

The results presented in Table 15 did not support our hypothesis, as only 25% (1 out of 4) of the handwriting performance domains demonstrated stronger correlations with the CCVPT under bootstrap analysis. In terms of handwriting speed, measured by the number of words written during the follow-up session, the correlation with the initial CCVPT scores was not stronger than with the TVPS-4 (difference = 0.11, 95% CI = -0.20 to 0.38). Similarly, no stronger correlations were found for handwriting accuracy (difference = 0.09, 95% CI = -0.22 to 0.36) or legibility (difference = 0.24, 95% CI = -0.13 to 0.78). To be more specific, within the legibility domain, the correlations in both the character (difference = 0.18, 95% CI = -0.16 to 0.68) and component subdomains (difference = 0.22, 95% CI = -0.11 to 0.74) did not exceed those observed with the TVPS-4. Notably, stronger correlations were observed between the CCVPT scores and parent-reported handwriting performance (difference = 0.39, 95% CI = 0.05 to 0.80).

In summary, four out of five hypotheses (80%) were confirmed, surpassing the 75% threshold, thereby supporting the CCVPT's good construct validity. Table 16 provides a summary of each hypothesis and whether it was supported by the results. The outcomes showed general consistency with the hypothesized relationships.

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Chapter 4 Discussion

4.1. Contribution

A standardized visual perception assessment tool, the CCVPT, was developed in the present study. The CCVPT incorporates the hierarchical features of Chinese characters and addresses three domains related to handwriting performance: visual identification, visual-spatial perception, and visual memory. The psychometric properties of the CCVPT were evaluated following the COSMIN guidelines. A total of 51 lower-grade students from Taiwan participated in the study. The results demonstrated good internal consistency, moderate to good test-retest reliability, acceptable measurement error, and satisfactory content and construct validity. The CCVPT can serve as an effective tool for evaluating visual perception abilities related with Chinese handwriting difficulties in children. In conclusion, the CCVPT exhibits good reliability and validity, supporting its clinical utility in assessing visual perception abilities among lower-grade children.

4.2. Internal Consistency Reliability

The CCVPT demonstrated good internal consistency reliability across all three subtests and the total score, with Cronbach's α values ranging from 0.71 to 0.89. This indicates that the test items consistently measure visual perception abilities and that the CCVPT is suitable for group-level comparisons in lower-grade children (Aaronson et al., 2002). Furthermore, comparable reliability coefficients between first- and second-grade students support the overall internal consistency of the CCVPT across different grade levels. Notably, internal consistency was slightly higher in second-grade students compared to first graders. Similar trends have been reported in other standardized assessments, suggesting that increased age is often associated with greater reliability due to more consistent engagement and test comprehension (Kaufman & Kaufman, 2004; Martin, 2017).

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Compared to other visual perception assessments, the CCVPT demonstrates comparable internal consistency. The Test of Visual Perception of Chinese Characters (TVPCC) developed by 洪儷瑜 (1997) reported varied internal consistency, with Cronbach's α ranging from 0.53 to 0.91 (N = 93, second-grade students), while the TVPS-4 by Martin (2017) demonstrated more stable reliability, with Cronbach's α values ranging from 0.71 to 0.98 for lower-grade children. Thus, these comparisons suggest that the CCVPT achieves comparable internal consistency to other commonly used tools, supporting its suitability for assessing visual perception in lower-grade children.

4.3. Test-retest Reliability

The CCVPT demonstrated moderate test-retest reliability in subtest of visual identification (ICC = 0.62) and visual memory (ICC = 0.61); and good reliability in visual-spatial perception (ICC = 0.77) and the total score (ICC = 0.87). Compared to other visual perception assessments, the CCVPT demonstrates comparable test-retest reliability. The Test of Visual Perception of Chinese Characters reported Pearson's r values ranging from 0.27 to 0.96, with the lowest reliability observed in the sequential memory subtest (N = 20, second-grade students). Similarly, the TVPS-4 demonstrated Pearson's r values ranging from 0.46 to 0.97, with the sequential memory subtest again showed the weakest reliability. The differences in test-retest reliability across the three CCVPT subtests may be attributed to variations in attentional demands or cognitive complexity associated with each task. For the visual identification subtest, the moderate reliability might be explained by the restricted score dispersion, as participants' scores tended to be on the higher side, potentially limiting score variability and reducing stability across administrations. This suggests that the visual identification results should be interpreted with caution in future applications. In contrast, the visual-spatial perception subtest demonstrated good test-retest reliability, possibly due to the task's relative stability, lower susceptibility to

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attention fluctuations, and consistent cognitive demands. The moderate reliability observed in the visual memory subtest may reflect similar challenges reported in prior visual perception assessments, where attention variability was found to influence memory performance (Matsukura et al., 2007). Thus, fluctuations in attention or environmental distractions during testing may lead to variability in performance over time. In summary, the CCVPT exhibited moderate to good test-retest reliability across the subtests, and good reliability in the total score. When concerns arise regarding the stability of specific subtest results, referencing the total score may offer a more robust and comprehensive evaluation. Alternatively, a second administration of the subtest may help achieve a more stable assessment outcome if needed. Future research should focus on increasing the sample size to further validate these findings.

4.4. Measurement Error

The CCVPT demonstrated acceptable measurement error in visual identification ($MDC_{95}\%$ = 14.48%), visual-spatial perception ($MDC_{95}\%$ = 16.76%), and visual memory ($MDC_{95}\%$ = 13.43%) subtests, with all MDC95% values falling below the 30% threshold. The total score showed excellent results ($MDC_{95}\%$ = 8.56%), with the $MDC_{95}\%$ remaining under the more rigorous 10% threshold. In practical terms, the MDC value for the total score was 9.41 points. This indicate that a change of at least 10 points in the total score reflects a real change in the measured construct of the CCVPT at a 95% confidence level. In other words, if the score changes exceed this MDC_{95} value, there is less than a 5% probability that the change is due to random measure error. In conclusion, the $MDC_{95}\%$ values observed in the CCVPT are acceptable.

4.5. Construct Validity

The CCVPT demonstrated good construct validity, with four out of five hypotheses confirmed in the present study, which above 75% threshold of hypothesis testing approach.

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(1) The results support the first hypothesis, which examined the correlation between the CCVPT and another visual perception assessment. Specifically, the three subtests and the total score of the CCVPT had moderate correlations with the standard total score of TVPS-4 (r = 0.45–0.62, *p*s < .01). These findings suggest that the CCVPT and TVPS-4 both measure visual perceptual concepts, providing evidence for convergent validity. Among the subtests, the visual-spatial perception subtest showed the strongest correlation with the TVPS-4, likely because it includes multiple aspects also measured by the TVPS-4 (r = 0.65, *p* < .001). In contrast, the visual memory subtest showed the weakest correlation with the TVPS-4 (r = 0.45, *p* < .01). One possible explanation is that the TVPS-4 includes only a few subtests specifically targeting visual memory, which could limit the extent of shared variance (Martin, 2017). Moreover, the relatively low correlation between the visual identification subtest and the TVPS-4 (r = 0.46, *p* < .001) might be attributed to generally high scores with limited variability. This restriction in range likely has reduced the strength of the observed correlation (Erkek & Çekmece, 2023). Overall, these findings support the validity of the CCVPT in assessing visual perception abilities.

(2) The results supported the second hypothesis, which addressed the correlation between the CCVPT and a visual-motor integration assessment. Specifically, the three subtests and the total score of the CCVPT showed moderate correlations with the Beery VMI-4 (r = 0.43–0.53, *p*s < .01). Visual-motor integration is defined as the coordination of visual perceptual processing and fine motor execution (Beery & Beery, 2010). The observed associations suggest that the visual perception measured by the CCVPT are related to those required for visual-motor integration tasks. These moderate correlations align with findings reported in the Beery VMI-6 manual, which noted a similar correlation (r = 0.48) between visual perception and visual-motor

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integration (Beery & Beery, 2010). Prior research also supports the theoretical relationship between visual perception and visual-motor integration (Beery & Beery, 2010; Brown, 2012; Chou et al., 2025). Together, these findings support the construct validity of the CCVPT.

(3) The results supported the third hypothesis, which addressed the correlation between the CCVPT and handwriting performance. Moderate correlations were found with handwriting accuracy and legibility, while weaker associations were found for parent-reported handwriting performance. No significant relationship was observed with handwriting speed. These findings suggest that visual-perceptual abilities assessed by the CCVPT may have relationship with handwriting performance in school-aged children and were aligned with previous findings (Lee, 2022; Piazzalunga et al., 2023; van Doorn & Keuss, 1992).

Handwriting speed, as measured by the number of words written in two minutes, showed a weak correlation with the visual memory subtest of the CCVPT ($r = 0.38$, $p < .01$), but no significant association with the other subtests or the total score. Visual memory is considered a component of working memory, and this ability has been associated with handwriting speed (De Vita et al., 2021). Consistent with previous findings, the visual memory subtest of the CCVPT demonstrated a weak but significant correlation with handwriting speed in the present study. In contrast, the visual identification and visual-spatial perception subtests did not show significant associations with handwriting speed. This might be expected because these subtests do not emphasize time efficiency. Overall, these findings suggest that among the visual-perceptual abilities assessed by the CCVPT, visual memory may play a more prominent role in supporting handwriting speed. In addition to visual-perceptual skills, other non-visual-perceptual factors such as pencil grasp, posture, paper

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positioning, motor planning, and fine motor control are also likely to contribute to handwriting speed (Franzsen & Stewart, 2014).

Regarding handwriting accuracy, moderate correlations were found with all three CCVPT subtests and the total score (r = 0.43–0.54, *p*s < .01). The results suggest that the CCVPT incorporates visual features specific to the Chinese character, and that related visual perceptual skills may influence handwriting accuracy. In the copying task, the process involves identifying the characters presented on paper or a screen, analyzing the spatial relationships between strokes and components, retaining visual details in memory, and accurately reproducing them on paper (Feder & Majnemer, 2007). Therefore, visual identification, visual-spatial perception, and visual memory all play a role in handwriting accuracy. These findings were echoed a previous study that found deficits in visual perception were associated with increased writing errors in children (Benalcázar & Torres, 2018), together supporting the relationship between handwriting accuracy and visual perception performance.

Handwriting legibility, as evaluated by legibility domain of the CHLAC, demonstrated moderate correlations with all three subtests and the total score of the CCVPT (r = 0.50–0.63, *p*s < .01). These results indicate that the visual perception assessed by the CCVPT contributes meaningfully to handwriting legibility. Given that legibility can be evaluated at both the character and component levels, the findings imply a stronger association with component-level features, such as the proportion and spacing of strokes and components (王姝婷 et al., 2024). This aligns with the design of the CCVPT, which was developed based on the structural principles of Chinese character composition and incorporates fine visual detail.

Finally, parent-reported handwriting performance, as assessed by the CHEF, showed weak correlations with the visual memory subtest (r = 0.37, *p* < .01) and the

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total score of the CCVPT (r = 0.29, $p < .05$). However, no significant correlations were found with the visual identification (r = 0.13, $p = .348$) or visual-spatial perception subtests (r = 0.23, $p = .098$). These results suggest that among the visual-perceptual abilities assessed by the CCVPT, visual memory may have the strongest connection with handwriting performance as perceived by parents. The CHEF is a parent-report instrument that evaluates various dimensions of handwriting, including speed, accuracy, legibility, grasp ergonomics, and direction (張韶霞 & 余南瑩, 2012). Therefore, it may capture a more holistic view of handwriting performance, which could dilute the strength of associations with visual-perceptual abilities or specific skills. Additionally, some of the children had just entered first grade, and their parents may not have been fully familiar with their handwriting performance, potentially leading to underestimation or overestimation of their skills.

(4) The results supported the fourth hypothesis, which compared the correlations between the CCVPT and the TVPS-4 with various aspects of handwriting performance. Overall, the CCVPT showed stronger correlations than the TVPS-4 with all aspects of handwriting performance, including handwriting speed, accuracy, legibility, and parent-reported performance. These findings suggest that the CCVPT may be more sensitive to the specific visual-perceptual skills required for Chinese handwriting.

The stronger associations between the CCVPT and handwriting performance may be attributed to its incorporation of structural and visual features unique to Chinese orthography. These elements align more closely with the actual demands of Chinese handwriting than the geometric figures used in conventional assessments such as the TVPS-4. These results support previous findings that Chinese characters involve perceptual processing distinct from that assessed by the existing visual

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perception tools (Wu et al., 2014). For example, the TVPS-4 was developed based on geometric features and may not fully reflect the complex spatial and structural characteristics of Chinese characters (洪儷瑜, 1997; 陳奕全、葉素玲, 2009). As a result, such tools may underestimate or misrepresent visual perception abilities in children learning Chinese. This shows that the present study bridges assessment with the practical needs of Chinese handwriting.

In conclusion, these findings not only support the validity of the CCVPT but also underscore the importance of developing visual perception assessments that are culturally and linguistically appropriate. Tools such as the CCVPT, which are specifically designed for populations using the Chinese handwriting system, are essential for accurate evaluation and effective intervention planning. The results highlight a broader implication that visual perception assessments should be tailored to the writing systems and educational demands of the population being assessed.

(5) The findings did not support the fifth hypothesis, which proposed that the CCVPT would show stronger correlations than the TVPS-4 with various aspects of handwriting performance after six months in first-grade students. Specifically, handwriting speed, accuracy, and legibility did not exhibit stronger associations with the CCVPT compared to the TVPS-4; however, a stronger correlation was observed only between the CCVPT and parent-reported handwriting performance. For handwriting speed, the CCVPT did not show a stronger correlation with follow-up performance compared to the TVPS-4, possibly due to external factors diminishing the influence of visual perception. Similarly, for handwriting accuracy, the CCVPT also did not show a stronger correlation than the TVPS-4. In terms of handwriting legibility, the CCVPT did not outperform the TVPS-4 in its association with the total score, character subscale, or component subscale. Regarding parent-reported

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handwriting performance, a significant correlation was found only with the CCVPT. After six months, parents may have gained greater awareness of their child's writing, improving the accuracy of their reports. This suggests that the CCVPT better reflects real-world handwriting as perceived by parents.

Although the CCVPT did not consistently outperform the TVPS-4 in predicting overall handwriting performance at six-month follow-up, it demonstrated significant correlations with component-level legibility and with parent-report handwriting performance. These findings suggest that the CCVPT may still be useful in identifying specific handwriting difficulties in children learning Chinese, especially for the legibility of component arrangement and handwriting performance as perceived by parents, compared to the TVPS. Further research with larger samples is needed to examine its potential application in identifying handwriting-related difficulties.

4.6. Limitation

4.6.1. Sample size

The sample size of this study was adequate for assessing internal consistency and construct validity, but insufficient for evaluating test-retest reliability and measurement error (Prinsen et al., 2018) Previous research has recommended a minimum of 50 participants to obtain stable reliability estimates (Streiner & Norman, 2008). Therefore, the sample size of 20 in the present study may be insufficient to achieve optimal stability in the inter-class coefficients. Caution is advised when interpreting the test-retest reliability results, as the limited sample size may reduce the precision of the estimates. Small sample size may also have reduced the statistical power to detect significant associations in follow-up analyses. Some non-significant findings, such as handwriting accuracy and legibility, may reflect this limitation rather than a true lack of association,

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given their effect sizes (r > 0.30) suggest meaningful relationships. Future studies with larger samples are needed to strengthen the evaluation of the CCVPT's psychometric properties.

4.6.2. Sampling

This study adopted a convenience sampling method, with the majority of participants being male and right-handed. While some of these children received support from resource class, all of them passed cognitive screening, and their overall intellectual performance was above average. These sample characteristics may reflect a degree of selection bias, which may limit the generalizability of the study's findings.

4.7. Future Work

Future research aims to include preschool children and school-aged children with handwriting difficulties or relevant diagnoses. This will help explore the development of visual perception related to Chinese characters and its link to handwriting performance, serving as a reference for early identification and intervention. Subsequent studies may follow the COSMIN guidelines to further examine the structural validity and responsiveness of the assessment tool (Mokkink et al., 2016). Additionally, the item-level and person-level validity and reliability should be evaluated to better understand the relationship between item difficulty and individual ability.

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Chapter 5 Conclusions

The CCVPT includes three subtests covering visual identification, visual-spatial perception, and visual memory, was developed to systematically assess visual perceptual abilities related to Chinese handwriting in children. The results demonstrated good internal consistency across subtests and the total score, indicating that the items reliably measure the same underlying construct. Test-retest reliability ranged from moderate to good, confirming the stability of the test over a two-week interval. Measurement error was within acceptable limits for all subtests and excellent for the total score, reflecting strong sensitivity to change. In terms of construct validity, the CCVPT showed weak to moderate correlations with general visual perception tests, visual-motor integration, and handwriting performance. Notably, it demonstrated stronger associations with handwriting performance measures such as accuracy, legibility, and parent-reported handwriting performance, compared to commonly used visual perception tools. Although the CCVPT may not efficiently predict future handwriting performance, it demonstrated significant correlations with component-level legibility and parent-reported handwriting performance. Future studies with larger and more diverse samples are needed to further validate these findings.

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Tables

Table 1. Evidence of Relationship between Visual Perception and Handwriting Performance

	VI	VS	VM
Accuracy	+ (Li-Tsang et al., 2022) – (Hwang et al., 2024)	– (Li-Tsang et al., 2022) + (Hwang et al., 2024)	+ (Li-Tsang et al., 2022) – (Hwang et al., 2024)
Legibility	– (Tse et al., 2014) – (Hwang et al., 2024) + (Lee, 2022) – (Lee et al., 2016)	+ (Tse et al., 2014) – (Hwang et al., 2024) + (Lee, 2022)	– (Hwang et al., 2024)
Speed	– (Li-Tsang et al., 2022) – (Tse et al., 2014) – (Hwang et al., 2024) – (Tseng & Chow, 2000)	– (Li-Tsang et al., 2022) – (Tse et al., 2014) – (Hwang et al., 2024) – (Tseng & Chow, 2000)	– (Li-Tsang et al., 2022) – (Hwang et al., 2024) + (Tseng & Chow, 2000)

Note.*: VI, Visual Identification; VS, Visual-spatial perception; VM, Visual Memory;*
+, statistically significant; –, not statistically significant

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Table 2. The Summary of Previous Visual Perception Test Considering Chinese Character

Assessment	Author	Content	Age	Reliability	Validity
Test of Visual Perception of Chinese Characters	洪儷瑜 (1997)	Memory span, Sequential memory, Figure discrimination, Character discrimination, Component discrimination, Awareness of orthography	Grade 2-5	Internal consistency (Cronbach α = .42–.91), Test-retest reliability (r = .27–.96)	Content[2], Criterion-related[2], Construct validity[3]
Visual Process Assessment	蔡惠菁 (2004)	Visual memory, Visual discrimination	Grade 1	Internal consistency (Cronbach α = .86–.88), Split-half reliability (r = .48–.82)	Content[3], Structural validity[3]
Computerized Visual Perception Assessment Tool	吳慧珉 (2015)	Basic strokes, Compound characters, Single-component, characters	4-6y	Internal consistency (Cronbach α = .82–.92)	Structural validity[1]

***Note**. 1, Very good ; 2, Adequate; 3, Doubtful*

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Table 3. The structure of the Chinese Character Visual Perception Test

Visual Identification		
Item (3)	Shapes (5)	Difficulty (2)
1. Geometric Figure 2. Stroke 3. Component	Left-Right Horizontal	Simple (One Distractor) Difficult (Two Distractors)
	Top-Bottom Vertical	Simple (One Distractor) Difficult (Two Distractors)
	P-Shape	Simple (One Distractor) Difficult (Two Distractors)
	L-Shape	Simple (One Distractor) Difficult (Two Distractors)
	Enclosed	Simple (One Distractor) Difficult (Two Distractors)
Visual-Spatial Perception		
Item (4)	Shapes (5)	Difficulty (2)
1. Geometric Figure 2. Stroke 3. Component 4. Character	Left-Right Horizontal	Simple (Complete Change) Difficult (Change One Component)
	Top-Bottom Vertical	Simple (Complete Change) Difficult (Change One Component)
	P-Shape	Simple (Complete Change) Difficult (Change One Component)
	L-Shape	Simple (Complete Change) Difficult (Change One Component)
	Enclosed	Simple (Complete Change) Difficult (Change One Component)
Visual Memory		
Item (4)	Shapes (5)	Difficulty (2)
1. Geometric Figure 2. Stroke 3. Component 4. Character	Left-Right Horizontal	Simple (Single Word) Difficult (Two Words)
	Top-Bottom Vertical	Simple (Single Word) Difficult (Two Words)
	P-Shape	Simple (Single Word) Difficult (Two Words)
	L-Shape	Simple (Single Word) Difficult (Two Words)
	Enclosed	Simple (Single Word) Difficult (Two Words)

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Table 4. Demographic Characteristic of the Participants

	All (N=51)	**First-grade** (N=26)	**Second-grade** (N=25)
Age (years)	6.97 ± 0.63	6.44 ± 0.31	7.52 ± 0.34
Sex (male) (%)	33 (64.7%)	17 (65.4%)	16 (64.0%)
Dominant hand (right) (%)	44 (86.3%)	22 (84.6%)	22 (88.0%)
Class (general education) (%)	37 (72.5%)	19 (73.1%)	18 (72.0%)
RCPM (standard scores)	105.24 ± 13.00	104.19 ± 12.99	106.32 ± 13.18

Note. *RCPM, Raven's Colored Progressive Matrices*

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Table 5. Scores on the Chinese Character Visual Perception Test and Other Measures

	All (N=51)	First-grade (N=26)	Second-grade (N=25)
CCVPT (raw scores)			
VI	24.61 ± 3.54	23.96 ± 3.67	25.28 ± 3.35
VS	28.55 ± 5.71	27.85 ± 5.79	29.28 ± 5.64
VM	30.02 ± 4.46	28.58 ± 4.06	31.52 ± 4.43
Total Score	83.18 ± 11.93	80.38 ± 11.56	86.08 ± 11.84
TVPS-4 (standard scores)	108.25 ± 18.61	112.88 ± 9.57	108.00 ± 10.77
Beery VMI (standard scores)	96.24 ± 23.91	101.04 ± 13.09	99.42 ± 14.77
BCBL－Speed (words count)			
Near Speed	6.33 ± 3.64	3.77 ± 1.28	9 ± 3.38
Far Speed	6.22 ± 3.43	3.92 ± 1.20	8.60 ± 3.37
Total Speed	12.55 ± 6.88	7.69 ± 2.28	17.60 ± 6.42
BCBL－Accuracy (%)			
Near Accuracy	68.87 ± 26.19	50.82 ± 23.70	87.63 ± 11.14
Far Accuracy	76.76 ± 25.18	65.06 ± 27.53	88.93 ± 15.14
Total Accuracy	72.91 ± 22.45	58.01 ± 21.11	88.41 ± 9.73
CHLAC－Legibility (standard scores)			
Legibility	45.37 ± 10.03	41.00 ± 11.28	49.80 ± 5.22
Character	19.92 ± 4.38	18.77 ± 5.01	21.00 ± 3.04
Size	9.24 ± 3.25	8.58 ± 3.19	10.40 ± 2.93
Place	10.69 ± 2.75	10.19 ± 2.90	10.60 ± 2.61
Component	25.45 ± 6.83	22.23 ± 7.30	28.80 ± 4.33
Rotate	10.25 ± 2.70	9.08 ± 3.20	11.48 ± 1.19
Portion	7.53 ± 2.82	6.58 ± 2.70	8.52 ± 2.65
Space	7.67 ± 3.40	6.58 ± 3.68	8.80 ± 2.71
CHEF－Parent report (percentile rank)	25.08 ± 22.47	23.23 ± 20.64	27.00 ± 24.51

Note. *CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory; TVPS, Test of Visual Perceptual Skills－4th ed.; Beery VMI, Beery-Buktenica Developmental Test of Visual-Motor Integration－4th ed.; BCBL, Battery of the Chinese of Pupils; CHLAC, Chinese Handwriting Legibility Assessment for Children; CHEF, Chinese Handwriting Evaluation Form*

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Table 6. The Internal Consistency Reliability of the Chinese Characters Visual Perception Test

Cronbach α	**All** (N=51)	**First-grade** (N=26)	**Second-grade** (N=25)
CCVPT (raw scores)			
VI	0.71	0.69	0.73
VS	0.80	0.79	0.82
VM	0.74	0.67	0.75
Total Score	0.89	0.87	0.90

***Note**. CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory*

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Table 7. Participant Demographics for Test–Retest Reliability (N = 20)

	Participants (N=20)
Age (years)	7.16 ± 0.66
Sex (male) (%)	12 (60.0%)
Dominant hand (right) (%)	15 (85.0%)
Class (general education) (%)	19 (95.0%)
RCPM (standard scores)	105.10 ± 12.07

Note. *RCPM: Raven's Colored Progressive Matrices*

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Table 8. Chinese Characters Visual Perception Test scores from the first or second administration (N=20)

	First time	Second time
CCVPT (raw scores)		
VI	26.45 ± 3.02	26.20 ± 1.99
VS	30.85 ± 5.50	31.55 ± 4.73
VM	33.45 ± 2.98	33.95 ± 3.30
Total Score	90.75 ± 10.44	91.70 ± 8.52

Note. *CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory*

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Table 9. The Test-retest Reliability and Measurement Error of Chinese Characters Visual Perception Test

	ICC	r	SEM	MDC_{95}	$MDC_{95}\%$
CCVPT					
VI	0.62**	0.66**	1.57	4.34	14.48
VS	0.77***	0.78***	2.42	6.70	16.76
VM	0.61**	0.61**	1.94	5.37	13.43
Total Score	0.87***	0.89***	3.40	9.41	8.56

*p<0.05; **p<0.01; ***p<0.001

Note. *ICC, intraclass correlation coefficients; r, Pearson's correlation coefficients; SEM, standard error of measurement; MDC, minimal detectable change;*
CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory

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Table 10. Correlation between the CCVPT and TVPS-4, Beery VMI (N = 51)

	CCVPT			
	VI	**VS**	**VM**	**Total Score**
TVPS-4 (standard scores)	0.46**	0.65***	0.45**	0.62***
Beery VMI (standard scores)	0.43**	0.45**	0.50***	0.53***

※$p = 0.05$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Note. *CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory*

TVPS, Test of Visual Perceptual Skills — 4th ed.; Beery VMI, Beery-Buktenica Developmental Test of Visual-Motor Integration —4th ed.

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Table 11. Correlation between the CCVPT and Handwriting Performance (N = 51)

	CCVPT			
	VI	VS	VM	Total score
BCBL－Speed (words count)				
Near Speed	0.22	0.11	0.38 **	0.26
Far Speed	0.24	0.09	0.35 *	0.24
Total Speed	0.23	0.11	0.38 **	0.26
BCBL－Accuracy (%)				
Near Accuracy	0.45 **	0.35 *	0.49 ***	0.49 ***
Far Accuracy	0.32 *	0.40 **	0.43 **	0.44 **
Total Accuracy	0.45 **	0.43 **	0.54 ***	0.54 ***
CHLAC－Legibility (standard scores)				
Legibility	0.50 ***	0.58 ***	0.54 ***	0.63***
Character	0.33 *	0.45 **	0.38 **	0.46**
Size	0.28 *	0.33 *	0.37 **	0.38**
Place	0.20	0.33 *	0.17	0.28*
Component	0.51 ***	0.55 ***	0.54 ***	0.62**
Rotate	0.61 ***	0.57 ***	0.44 **	0.62**
Portion	0.24	0.34 *	0.44 **	0.40**
Space	0.33 *	0.38 **	0.38 **	0.42**
CHEF－Parent report (percentile rank)	0.13	0.23	0.37**	0.29*

※$p = 0.05$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Note. *CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory*

BCBL, Battery of the Chinese of Pupils; CHLAC, Chinese Handwriting Legibility Assessment for Children; CHEF, Chinese Handwriting Evaluation Form

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Table 12. CCVPT vs. TVPS-4: A Comparison of Correlations with Handwriting Performance (N = 51)

	CCVPT	TVPS-4	BCa bootstrap	
	Total score	Total score	Difference	95% CI
BCBL－Speed (words count)				
Total Speed	0.26	-0.22	0.47†	0.25 — 0.71
BCBL－Accuracy (%)				
Total Accuracy	0.54 ***	0.02	0.52†	0.31 — 0.74
CHLAC－Legibility (standard scores)				
Legibility	0.63**	0.15	0.48†	0.26 — 0.70
Character	0.46**	0.15	0.31†	0.12 — 0.56
Component	0.62**	0.13	0.49†	0.29 — 0.72
CHEF－Parent report (percentile rank)	0.29*	0.05	0.24†	0.05 — 0.53

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

†95% Confidence Interval does not include 0

Note. *CCVPT, Chinese Characters Visual Perception Test; TVPS, Test of Visual Perceptual Skills —4th ed.; BCBL, Battery of the Chinese of Pupils; CHLAC, Chinese Handwriting Legibility Assessment for Children; CHEF, Chinese Handwriting Evaluation Form*

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Table 13. Participant Demographics for Fifth Hypothesis Testing (N = 23)

	Participants (N=23)
Age (years)	6.88 ± 0.32
Interval (days)	158.61 ± 14.19
Sex (male) (%)	16 (61.5%)
Dominant hand (right) (%)	19 (73.1%)
Class (general education) (%)	17 (65.4%)
RCPM (standard scores)	105.70 ± 11.64

Note*. *RCPM: Raven's Colored Progressive Matrices

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Table 14. Scores on the Chinese Character Visual Perception Test and Other Measures at Initial and Six-Month Follow-Up (N = 23)

	Initial	**Follow-up**
CCVPT		
VI	24.52 ± 3.23	26.57 ± 2.43
VS	28.70 ± 5.03	29.83 ± 5.81
VM	28.78 ± 4.27	31.48 ± 3.20
Total Score	82.00 ± 10.60	87.87 ± 9.63
TVPS-4 (standard scores)	113.70 ± 9.28	—
Beery VMI (standard scores)	101.65 ± 13.80	103.65 ± 9.83
BCBL－Speed (words count)		
Near Speed	3.78 ± 1.35	6.26 ± 2.28
Far Speed	3.91 ± 1.24	5.57 ± 1.59
Total Speed	7.70 ± 2.42	11.83 ± 3.71
BCBL－Accuracy (%)		
Near Accuracy	52.74 ± 24.29	83.02 ± 13.24
Far Accuracy	69.28 ± 26.38	90.31 ± 12.54
Total Accuracy	61.00 ± 20.44	86.39 ± 8.94
CHLAC－Legibility (standard scores)		
Legibility	41.91 ± 11.38	49.22 ± 6.10
Character	19.04 ± 5.15	20.43 ± 3.68
Size	8.61 ± 3.16	10.04 ± 2.72
Place	10.43 ± 3.00	10.39 ± 2.69
Component	22.87 ± 7.32	28.78 ± 3.83
Rotate	9.22 ± 3.20	10.70 ± 2.32
Portion	6.70 ± 2.75	8.83 ± 2.79
Space	6.96 ± 3.74	9.26 ± 2.96
CHEF－Parent report (percentile rank)	25.70 ± 20.71	28.39 ± 21.03

Note*. CCVPT, Chinese Characters Visual Perception Test; VI, visual identification; VS, visual-spatial perception; VM, visual memory; TVPS, Test of Visual Perceptual Skills — 4th ed.; Beery VMI, Beery-Buktenica Developmental Test of Visual-Motor Integration — 4th ed.; BCBL, Battery of the Chinese of Pupils; CHLAC, Chinese Handwriting Legibility Assessment for Children; CHEF, Chinese Handwriting Evaluation Form*

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Table 15. CCVPT vs. TVPS-4: Predicting Handwriting Performance in First-grade Students Six Months Later (N = 23)

	CCVPT	TVPS-4	BCa bootstrap	
	Total score	Total score	Difference	95% CI
BCBL－Speed (words count)				
Total Speed	0.06	-0.05	0.11	-0.20 — 0.38
BCBL－Accuracy (%)				
Total Accuracy	0.31	0.21	0.09	-0.22 — 0.36
CHLAC－Legibility (standard scores)				
Legibility	0.32	0.07	0.24	-0.13 — 0.78
Character	0.02	-0.15	0.18	-0.16 — 0.68
Component	0.49*	0.27	0.22	-0.11 — 0.74
CHEF－Parent report (percentile rank)	0.48*	-0.01	0.39†	0.05 — 0.80

*p<0.05; **p<0.01; ***p<0.001

Note. *CCVPT, Chinese Characters Visual Perception Test; TVPS, Test of Visual Perceptual Skills－4th ed.; BCBL, Battery of the Chinese of Pupils; CHLAC, Chinese Handwriting Legibility Assessment for Children; CHEF, Chinese Handwriting Evaluation Form*

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Table 16. Hypotheses for Testing Construct Validity of the CCVPT

Hypothesis	Concept	CCVPT		
		Expected	**Actual**	**Confirmed?**
1. There are at least weak to moderate correlations between CCVPT scores and the TVPS-4	**Visual perception**	0.20 – 0.69 $p < 0.05$	0.62	**Yes**
2. There are at least weak to moderate correlations between CCVPT and the copy subtest of Beery VMI-4	**Visual-motor integration**	0.20 – 0.69 $p < 0.05$	0.53	**Yes**
3. There are at least weak to moderate correlations between CCVPT and Chinese handwriting performance	**Handwriting Performance**	> 75% Confirmed	75% Confirmed	**Yes**
	Speed	0.20 – 0.69 $p < 0.05$	0.26 (p>0.05)	No
	Accuracy		0.54	Yes
	Legibility		0.63	Yes
	Parent report		0.29	Yes
4. There is a stronger correlation between CCVPT and Chinese handwriting performance	**Handwriting Performance**	> 75% Confirmed	75% Confirmed	**Yes**
	Speed	CCVPT > TVPS-4	>	No
	Accuracy		>	Yes
	Legibility		>	Yes
	Parent report		>	Yes
5. CCVPT performance in first-grade children shows stronger correlation with Chinese handwriting performance after six months of formal instruction	**Handwriting Performance**	> 75% Confirmed	25 % Confirmed	**No**
	Speed	CCVPT > TVPS-4	=	No
	Accuracy		=	No
	Legibility		=	No
	Parent report		>	Yes

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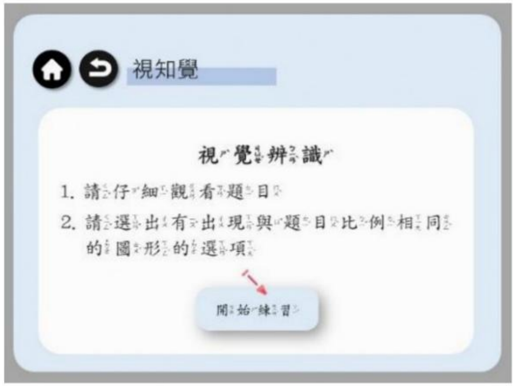
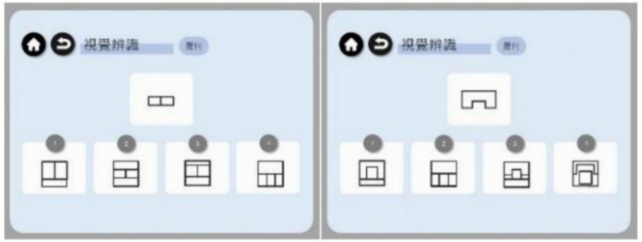
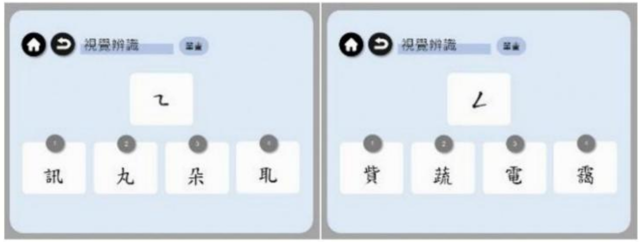
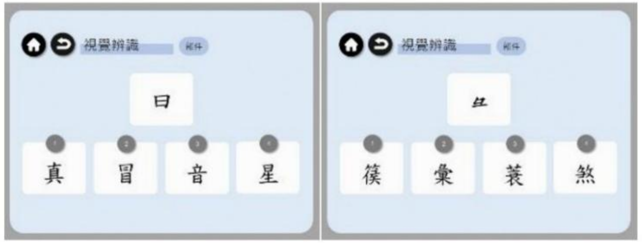
Appendix A

The Definitions and Example Items of the Chinese Characters Visual Perception Test (CCVPT)

Subtest	Operational definition	Item example	
Visual Identification	The ability to distinguish object features, such as identifying a specific form that may vary in size or be embedded within other shapes, and determining whether objects are the same across different backgrounds 	Geometric figure	
		Stroke	
		Component	

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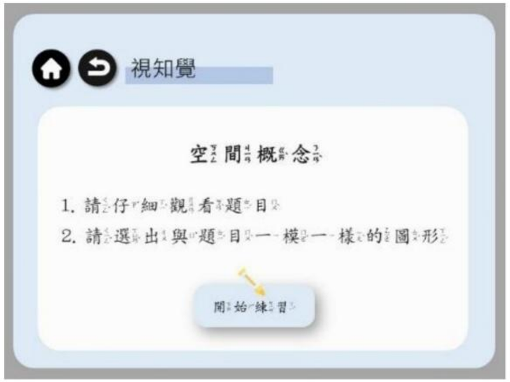
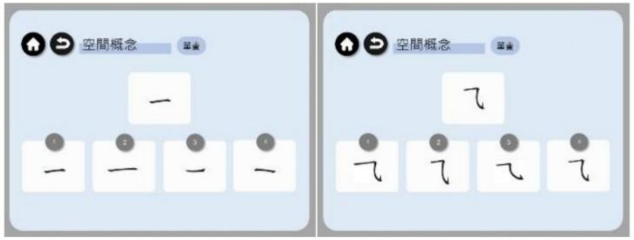
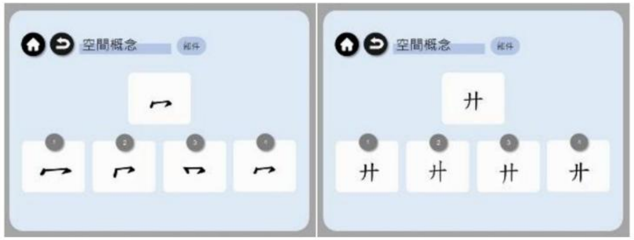
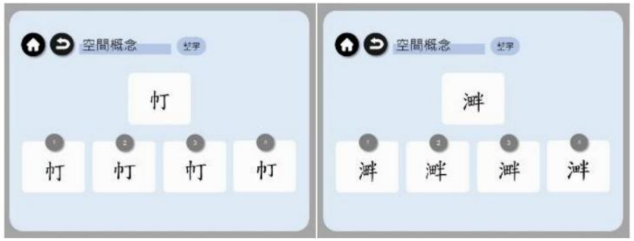
Subtest	Operational definition	Item example	
Visual-Spatial Perception	The ability to understand the spatial relationships and relative positions within an object, such as judging proportions and sizes of components, and determining exact characteristics of two forms by matching them among a group of similar forms 	Geometric figure	
		Stroke	
		Component	
		Character	

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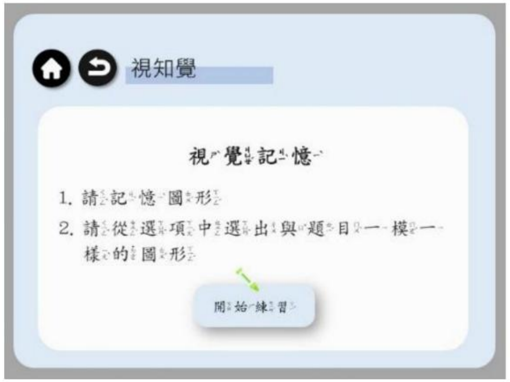
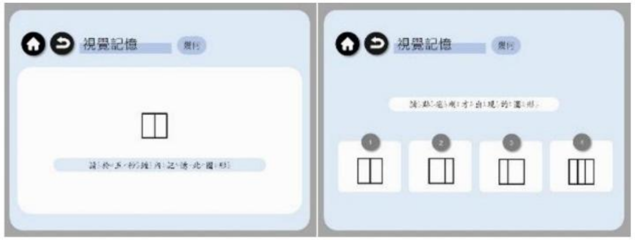
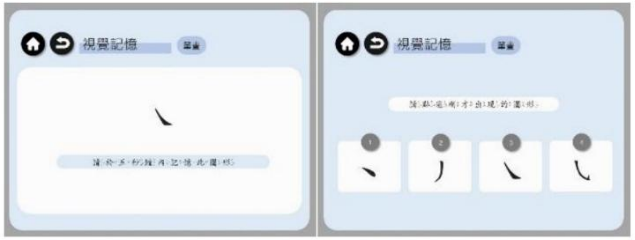
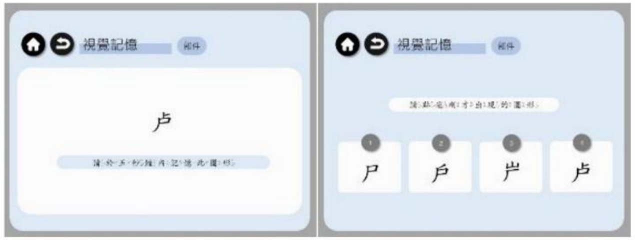
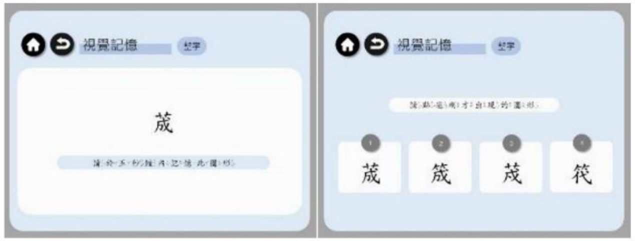
<table>
<tr><th>Subtest</th><th>Operational definition</th><th colspan="2">Item example</th></tr>
<tr><td rowspan="4">Visual Memory</td><td rowspan="4">The ability to store and retrieve visual information, such as recalling and identifying the same form as a previously viewed stimulus among a group of similar forms after a 5 seconds exposure

</td><td>Geometric figure</td><td>
</td></tr>
<tr><td>Stroke</td><td>
</td></tr>
<tr><td>Component</td><td>
</td></tr>
<tr><td>Character</td><td>
</td></tr>
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