Project Title	**:**	The use of perceptual training in a mobile application to improve Chinese reading performance in children with dyslexia
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Final Report

by

Principal Investigator

The use of perceptual training in a mobile application to improve Chinese reading performance in children with dyslexia

(a) Abstract

Children with dyslexia face huge difficulty in improving their reading skills. While many intervention strategies have been developed, relatively few have been demonstrated to be useful to improve reading. Support for students with Chinese dyslexia is currently highly limited. The project served as a proof of concept of whether perceptual training can be adapted in the form of a mobile application and serve as an intervention program for students with Chinese dyslexia to improve Chinese reading performance. With a randomized controlled trial design, perceptual training has been shown to be able to effectively improve Chinese word reading performance of children with developmental dyslexia. Our team has also successfully developed a prototype of a mobile application that works on different platforms including websites, iOS and Android platforms. Finally, our understanding of development of reading fluency has been enhanced by showing that perceptual training plays an important role in improving reading performance. Theoretically, in contrast to some researchers' rejection of visual perception as a possible cause of developmental dyslexia, the current findings highlight the effectiveness of perceptual training in improving Chinese word reading in children with developmental dyslexia. It calls for adding perceptual processes of words to the considerations of building a multifactorial model of developmental dyslexia. Practically, students with developmental dyslexia should consider using this app as an additional learning tool to complement the current intervention.

(225 words)

(b) Keywords

1. Perceptual training

2. dyslexia

3. Chinese word reading

4. word recognition

5. mobile application

(c) Introduction

Chinese reading has been one of the major focuses in language education in Hong Kong. According to the Education Bureau, the development of Chinese reading skill is one of the main focuses in Chinese learning starting from the fourth year of primary school education onward until the end of secondary school education.

The project aims at developing a tool that helps students with dyslexia to acquire accurate and efficient recognition of Chinese characters. The efficiency in reading Chinese characters will provide a solid foundation for students to acquire more advanced skills in Chinese reading, and to enjoy Chinese reading in a wider range of areas and topics with more in-depth understanding.

(d) Review of literature of the project

Reading and Developmental Dyslexia

Learning to read is an essential skill to acquire in normal schooling experience. However, it is extremely difficult for some children affected by developmental dyslexia. Developmental dyslexia is characterized by difficulties developing accurate or fluent word recognition, spelling and decoding of words despite adequate instruction, intelligence and sensory abilities (American Psychiatric Association, 2013). Notably, comparing with dyslexia in alphabetic languages, Chinese dyslexia is thought to involve different neural mechanisms (Siok, Niu, Jin, Perfetti, & Tan, 2008) and different deficiencies in cognitive processing (Shu, McBride-Chang, Wu, & Liu, 2006).

The cause(s) of dyslexia are hotly debated. Theoretical proposals range from impaired ability to perceive and manipulate sounds of spoken words (“phonological awareness”; Goswami & Bryant, 1990; Mattingly, 1972), deficits in rapid processing of auditory speech input (Goswami, 2011; Tallal, 1980, 2004), deficits in visual processing along a certain pathway (“the magnocellular-dorsal pathway”; Livingstone, Rosen, Drislane, & Galaburda, 1991; Stein & Walsh, 1997), attentional deficit (Vidyasagar & Pammer, 2010), deficits in processing crowded visual images (Gori & Facoetti, 2015), excess neural noise in the brain regions important for reading (Hancock, Pugh, & Hoeft, 2017), etc. While the cause(s) of dyslexia remain elusive, it is a general consensus that developmental dyslexia is a complex disorder with multifactorial origins involving different levels, including genes, brain structure and/or functions, and cognition (Hancock et al., 2017).

In addition to identifying the causes and underlying mechanisms of developmental dyslexia, researchers are also actively searching for interventions that can effectively improve reading performance for children with dyslexia. However, the proposed interventions are far from being fully successful. The most common remediation is to train sub-skills of reading that involves phonological awareness or rapid auditory processing, which unfortunately do not automatically lead to better reading abilities (Agnew, 2004; Galuschka, Ise, Krick, & Schulte-Körne, 2014; Strong, Torgerson, Torgerson, & Hulme, 2011).

Although a few recent intervention studies have demonstrated success in improving reading, questions and challenges remain. For example, playing action video games or learning to detect orientation of lines embedded in many distracting lines improve reading performance (Franceschini et al., 2013; Meng, Lin, Wang, Jiang, & Song, 2014). However, it remains elusive why these interventions are useful. For example, why are detecting lines or action video games relevant to the ability of reading words? Since researchers do not provide comprehensive accounts of why these children have difficulties with reading and spelling, it is possible that they may not have targeted on the crux of the problems in dyslexia.

(e) Theoretical and/or conceptual framework of the project

Perceptual training improves visual recognition performance

Lab training studies suggest that perceptual training may be very useful in improving reading performance in individuals with dyslexia (Gori & Facoetti, 2014). Perceptual training typically involves repeated and speeded presentation of visual images so as to push the visual perceptual limit of the participants (Bukach, Gauthier, & Tarr, 2006; Goldstone, 1998; Sasaki, Nanez, & Watanabe, 2010). For example, in a commonly adopted paradigm (e.g., Gauthier & Tarr, 1997; Gauthier, Williams, Tarr, & Tanaka, 1998), participants are presented highly similar visual images on computer monitors and they need to discriminate between them by key presses. In the course of training, participants become faster and more accurate, leading to highly efficient recognition of the visual objects at the end of the training.

Our research and that of others have shown that visual perceptual performance can be greatly improved within a few hours of training. For example, novices learned to differentiate highly similar, novel three-dimensional objects generated by computers within 8-10 hours of laboratory training, and their recognition speed improved from about 1.5 seconds to 0.8 seconds per object (Gauthier et al., 1998; A. C.-N. Wong, Palmeri, & Gauthier, 2009; see Figure 1).

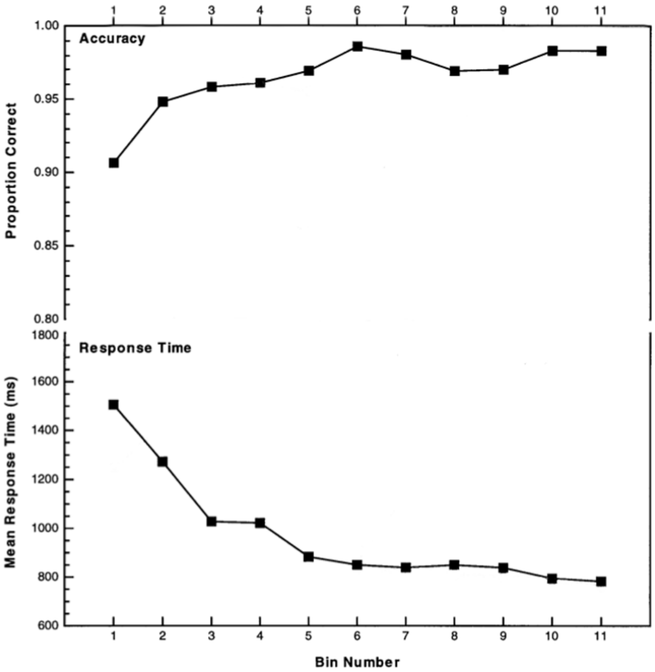

Figure 1. Perceptual training led to a gradual improvement in recognition accuracy and in the speed of making correct response with a set of computer-generated novel objects called ‘Greebles’ (Adapted from Figure 4, Gauthier et al., 1998).

Such short training also leads to changes in the activity of various visual areas of the brain, and in some cases large-scale changes in the relevant neural network (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; A. C.-N. Wong, Palmeri, Rogers, Gore, & Gauthier, 2009; Y. K. Wong, Folstein, & Gauthier, 2012; Figure 2). Despite the short-term nature of the training, behavioral improvement in performance have been shown to last for at least 6 months (Y. K. Wong et al., 2012).

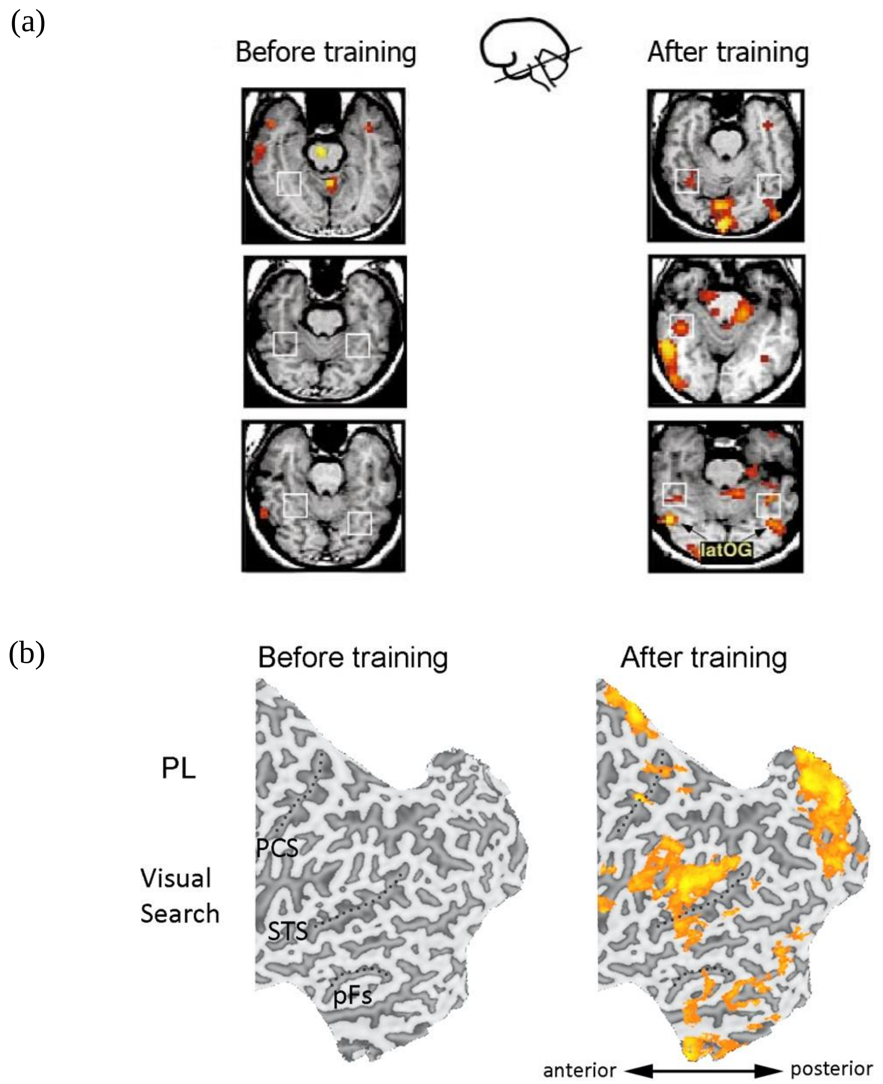

Figure 2. The large scale changes in the brain after perceptual training. (a) A wide range of brain areas in the ventral occipitotemporal cortex was activated by the computer-generated novel objects ‘Greebles’ following the perceptual training on recognizing ‘Greebles’ (Adapted from Gauthier et al., 1999). (b) A widespread neural network was engaged following the perceptual training on recognizing the orientation of a set of computer-generated novel objects ‘Ziggerins’ (Adapted from Y. K. Wong et al., 2012).

Perceptual training improves reading performance

More directly, research suggests that perceptual training can effectively improve reading rate in different domains. In one study, the maximum speed of Roman letter reading in visual periphery increased by 41% after merely 4 hours of perceptual training for normal adults(S. T. L. Chung, Legge, & Cheung, 2004; see also Bernard, Arunkumar, & Chung, 2012; S. T. L. Chung & Truong, 2013; He, Legge, & Yu, 2013). Our recent study has also shown that the speed of music reading increased 10 times after 8 hours of perceptual training (Y. K. Wong & Wong, 2016). Specifically, participants could recognize music sequences of 4 to 5 notes at 80% accuracy when the sequences were presented for about 1.2 seconds in the first training session, but after eight hours of training they could attain the same level of accuracy even when a similar sequence was presented for just 0.11 seconds.

Perceptual training differs from many other reading-related training paradigms in that the former emphasizes recognition accuracy of the briefly presented words, without attempting to enrich the semantic association of the vocabularies, to utilize any contextual information of the words, or to require any interpretation of the materials directly or indirectly. It focuses on relaxing the sensory and/or perceptual bottleneck in word recognition, which serves as solid foundation to support efficient reading.

Perceptual training as remediation for developmental dyslexia

Traditional research does not consider visual processes as core deficits of developmental dyslexia (Gabrieli, 2009; Goswami, 2003; Hornickel & Kraus, 2013), which is perhaps the reason why visual perceptual training has not been applied in the design of intervention programs. However, there are several reasons to believe that perceptual training can be an effective remediation for developmental dyslexia, or even prevention programs for children at risk of developing dyslexia (Gori & Facoetti, 2014).

First, recent studies suggest that developmental dyslexia is related to multiple aspects of visual processing deficits (see review in Stein & Kapoula, 2012). For example, visual crowding, the difficulty in recognizing an object when it is surrounded by other objects, is thought to be a general bottleneck of object recognition and is a major limitation of reading rate (see review in Pelli & Tillman, 2008). Recently, visual crowding has been proposed to be a candidate core deficit in dyslexia (Gori & Facoetti, 2015). Importantly, our lab training work has already demonstrated that brief perceptual training can effectively reduce visual crowding experienced by individuals when they read musical notation (Y. K. Wong & Wong, 2016). It suggests that perceptual training may reduce visual crowding in word reading, thus enhancing reading performance in students with dyslexia.

Second, it is well established that perceptual training of visual object identification leads to changes in the ventral occipitotemporal region of the brain (Gauthier et al., 1999; A. C.-N. Wong, Palmeri, Rogers, et al., 2009; Y. K. Wong et al., 2012). This brain region, including the visual word form area (VWFA) in the left hemisphere, is thought to be closely related to reading (Dehaene & Cohen, 2011; Price & Devlin, 2011). It is of no surprise that this is also one of the most commonly observed regions showing deficient activity patterns in developmental dyslexia (McCandliss, Cohen, & Dehaene, 2003; Paulesu, 2001; Shaywitz et al., 2002). Overall, these suggest that perceptual training may help enhance reading performance in students with dyslexia by engaging the ventral occipitotemporal part of the brain.

Third, perceptual training is highly efficient, cost-effective, fun, accessible and catered for individual learning needs. It efficiently brings about sustained improvement in visual performance within only a few hours of training (Y. K. Wong et al., 2012). It is completely computerized and does not require any instructor or parent to sit beside the students during training, making it cost- and labour-saving. It is typically gamified, so students find it fun with a great sense of achievement when progressing through levels of the training game. With recent technological advances, perceptual training can be easily adapted to the format of mobile applications, which makes it highly accessible to students given the high prevalence of smart phones in Hong Kong nowadays. Finally, it caters for individual learning needs as students can learn and proceed in the training according to their own pace. Overall, perceptual training is highly practical and suitable as remediation for students with dyslexia.

To our best knowledge, perceptual training with Chinese characters has not been applied to interventions of students with dyslexia, either in alphabetic languages or in logographic languages such as Chinese. Though there are other computer training protocols available for students with dyslexia (e.g., the 'Read & Write' Project; 喜閱寫意), the learning protocol is substantially different from that of perceptual training in principle.

(f) Methodology

The aim of the proposed project is to examine whether perceptual training improves Chinese reading performance in students with developmental dyslexia. Students in P.3 to P.6 who have already been clinically diagnosed to have developmental dyslexia were recruited as participants.

The Perceptual Training

The perceptual training consisted of two parts, one is the computerized training performed on the in-house developed mobile application supported by this project, and the other was a face-to-face training on rapid automatized naming.

The Training on the Mobile Application. In this game, the goal of the player is to build a planet by adding elements into it (Figure 3). In general, they can pass a game level by attaining 90% accuracy or above, and gain more elements for the planet by passing higher levels of each game.

Figure 3. The original empty planet (left) and the fully developed planet (right) in the mobile application.

Games 1-3 (Game Category 1) aimed to improve the visual perceptual performance of the participants with Chinese characters, while Game 4-9 was to teach participants to link the pronunciation of the characters with the visual form and raise the processing fluency of visual and auditory information of the characters. Game 4 belonged to Game Category 2 that ensured participants to learn the pronunciation of all the trained characters, while Games 5-9 belonged to Game category 3. Participants had to complete Game Category 2 before proceeding to Game Category 3 because all games in Game Category 3 involved listening to spoken characters. For all games, the difficulty level of higher levels was generally increased by increasing the number of characters presented, decreasing the presentation time of the visual and/or audio stimuli, and decreasing the time window allowed for response. There were two sets of game parameters with different difficulty levels since we had no idea how fast participants would be able to progress to the later levels. When participants completed 90% of the levels for the fundamental set (Set 1), they proceeded to the advanced set (Set 2) to continue their training.

The tasks in the training game are described briefly here. (1) Game 1 was a sequential matching task, in which participants saw a briefly presented sequence of Chinese characters. Then they needed to choose the one they just saw among two highly similar choices; (2) Game 2 was a visual search task, in which participants needed to find a pair of Chinese characters among a matrix of characters; (3) Game 3 was reading-like visual search task, in which participants were first presented a target character, and they had to find all the target characters within lines of presented characters. The task was made reading like by the additional requirement for any correct responses that they had to select the characters according to the left-to-right reading direction; (4) Game 4 was an audiovisual matching task, in which participants selected the spoken character that they heard among several characters; (5) Game 5 was similar to an audiovisual version of Game 1, except that the stimuli was both presented visually and auditorily; (6) Game 6 was an audiovisual search task, in which participants heard a sequence of characters. They were required to select all of the spoken characters among one or multiple rows of characters. For the response to be considered correct, the order of selecting the characters must follow the reading direction, i.e., the selection must be performed from left to right and from the top to the bottom row; (7)

Game 7 was a simplified dictation task, in which participants heard a sentence that defined a character with context with minimal confusion ,e.g., “冰水嘅冰”. Then they were presented several options for each part of the character, e.g., 氵冫亻 for the left part of the character 冰, and were required to select the parts that formed the indicated character correctly; (8) Game 8 was a mismatch detection task, in which participants were visually and auditorily presented a sequence of Chinese characters, in which one or multiple characters could be mismatched. They were required to select the mismatched characters in the order of the left-to-right reading direction. To help participants attend to the correct part of the question, the levels began by highlighting a small subset of characters in black when they were being read out among other grey characters. The highlighted subset would increase in sizes until all the characters were highlighted at once, i.e., no attention cue was provided.

The Face-to-Face Training on Rapid Automatized Naming. The goal of this training was to help participants improve the association and fluency of processing between the visual perceptual processes and processes in other modalities required in reading. In this training, participants were required to read out a list of numbers from left to right and from the top to the bottom lines. They were required to read as quickly and as accurately as possible. They were motivated to complete this task faster and meet an individually-defined target time, which was the mean response time of their performance from the last session. To ensure that they would not trade accuracy with speed, only all-correct trials would be recorded. In the first session, they started with reading aloud 8 digits that were either presented in one or two rows, and gradually moved on to reading 16 or 40 digits if they met a certain speed requirement. Their average response time per digit was recorded during the first session and the last session of the school training. They performed this task for about 2-3 minutes each time, and they were called up by the experimenter individually whenever time allowed.

Prepost Tests

The three prepost tests performed by each participant were identical in design, but different in the exact characters used in the testing to minimize improvements simply caused by familiarity with the testing materials.

Each test included two word reading measures and eight cognitive constructs, and each construct was examined with three tasks. Participants performed each test in a fixed order to reduce individual variability in task performance. Each task provided short practices at the beginning, followed by experimental trials with no feedback. All spoken stimuli were pre-recorded by a native speaker of Cantonese, and were automatically presented with a computer program. All the spoken responses were recorded by the computer for grading and for checking purposes. Each testing session lasted for about 2-3 hours with abundant chances for students to take rest in between tasks.

Word Reading. Word reading performance was examined with two tasks, the non-speeded reading and speeded-reading task. In *non-speeded reading*, participants were presented a series of characters, one at a time, on the computer screen. They were required to read aloud each character, or use the mouse to click onto the question mark to skip the question. They were encouraged to think about it if needed and try their best to make a guess. In *speeded reading*, participants were presented 72 characters arranged in 6 different rows. They were required to read aloud the characters from left to right, and from the top row to the bottom row as accurately and as quickly as possible within 30s. For both tasks, both characters used in the training ('trained characters') and those not used in the training ('transfer charcters') were used to examine whether their reading performance, if any, generalized to untrained transfer characters. For both tasks, the number of correctly read characters were used as the dependent measure.

1. Visual attention. Visual attention was measured with three tasks. (1) For distributed visual spatial attention, participants saw four mathematical symbols briefly for 150ms, followed by a red dot cueing one of the four symbol positions. Then they were required to select the symbol at the cued position among eight choices with no time limit. (2) For focused visual spatial attention, it was similar to the distributed visual spatial attention task except that the cue was presented before the four symbols. (3) For serial visual attention, participants were presented a target symbol on top of the screen, below which was many lines of randomly ordered symbols. Participants were required to find as many target symbol as possible by mouse clicking within 30s. They also performed the task with a black square as the target, and with lines of black and white squares. Since the black square tends to pop out among the white squares, the task demand on visual attention was minimum in this condition such that it allows us to control for individual differences in visuomotor abilities.

2. Character recognition. Character recognition was measured with three tasks. (1) For sequential matching, participants saw a multi-character target sequence briefly, followed by two highly similar sequences. They were required to select the target sequence without time limit. The first sequence was presented in varied timing from 146ms to 2000ms so as to provide a range of difficulty levels. (2) For same-different matching, the task was similar to that of sequential matching except that there was only one sequence presented after the target sequence, and participants were required to determine if the two sequences were identical. (3) For simultaneous matching, participants were required to judge whether two character sequences on the screen were identical. The sequences disappeared within 676ms to 2000ms, while the response was not time limited and could still be made after stimulus disappeared. All tasks were performed with trained characters, transfer characters and digits, which controlled for general perceptual ability non-specific to Chinese character recognition. The accuracy corrected for guessing was used as the dependent measure for all tasks.

3. Phonological awareness. Phonological awareness was measured by three tasks. (1) For the oddball task, participants saw three grey letters of ‘A B C’ on the screen and heard three spoken characters sequentially with the corresponding letter highlighted in black. They were required to judge which character sounded more differently than the other two by clicking onto the corresponding letter without time limit. (2) For phonological verification, participants verified the result of a given phoneme manipulation of a syllable and heard questions in the format of “if the word <yat1> lost the sound of <y>, would it become <aa1>?” They were required to judge the correctness of the provided answer by mouse clicking without time limit. (3) For phonological segmentation, participants judged whether a syllable contained a certain phoneme or rime and heard questions in the format of ‘does the word <ma1> have the sound of <n>?’ They were required to judge yes or no by mouse clicking. The accuracy corrected for guessing was used as the dependent measure for all tasks.

4. Visuoauditory association. Visuoauditory association was measured by three tasks. (1) For sequential matching, participants were visually and auditorily presented a sequence of characters, and judged if the visual and spoken characters matched. They clicked either ‘yes’ or ‘no’ without time limit. (2) For mismatch identification, participants were visually and auditorily presented a sequence of characters, and judged which character was the misread. There was always one misread character in each question. Participants clicked on the character directly without time limit. (3) For mismatch counting, the task was similar to that of mismatch identification except that the number of mismatch ranged from zero to two. Participants were required to count the number of mismatched characters by clicking onto the numbers of '0 1 2' on the screen without time limit. The accuracy corrected for guessing was used as the dependent measure for all tasks.

5. Rapid automatized naming (RAN). RAN was measured with the same task with three different types of stimuli, namely digits (2,4,6,7,9), color circles (blue, green, yellow, red and black) and objects (car, table, eye, tree and shoe). The choice of the digits followed that used in standard tests of RAN (Norton et al., 2012). The colors were selected among the most distinctive major colors. The objects were selected among simple objects that could be consistently named with a single character (corresponding to a single syllable). During each trial, 40 stimuli were presented on the screen, and participants were required to read aloud all of them from left to right and from the top to the bottom row. They were required to read as quickly and as accurately as possible. When they finished reading, the experimenter would press the spacebar to stop the recording. The time required for finish naming all the stimuli aloud contributed to the dependent measure for all tasks.

6. Executive function. Executive function was measured with three tasks. (1) For working memory, participants heard a sequence of digits and they were required to report the digits in the same order or a reversed order without time limit. For each ordering, the sequence of digits increased by one digit for each correct response, and the testing stopped with an incorrect response. The sum of the number of digits in the final correctly performed digit sequence for each order was used as the dependent measure. (2) For inhibitory control, participants were required to say aloud the opposite meaning of a presented image as quickly and as accurately as possible. There were four pairs of pictures with opposite meanings, including up-down, black-white, boy-girl and fat-thin (Figure 4). The average response time of the voice onset of the correct trials served as the dependent measure. (3) For task switching, the participants were presented a bar during each trial, either in red or green color, and either in straight or horizontal orientation (Figure 5). They were required to describe the color of the bar when there was a dotted frame presented around the bar as accurately and as quickly as possible, and describe the orientation of the bar when there was no frame. The task switching cost was calculated by the inverse efficiency score, i.e., the $[(RT_{TaskSwitched} / Accuracy_{TaskSwitched}) - (RT_{NonTaskSwitched} / Accuracy_{NonTaskSwitched})]$ (Hughes et al., 2014).

(a) (b) (c) (d)

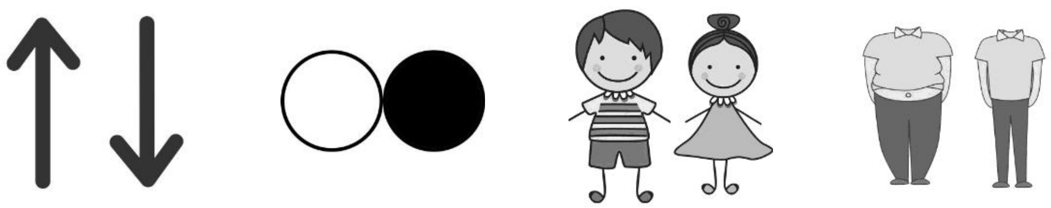

Figure 4. The pictures used in the inhibitory control task of the executive function measure, including (a) up-down, (b) black-white, (c) boy-girl and (d) fat-thin.

(a) (b) (c) (d)

Figure 5. The stimuli used in the task switching task under the measure of executive function, which included the green bars (a-b), red bars (c-d), the straight bars (a, c) and horizontal bars (b, d).

7. Morphological awareness. Morphological awareness was measured with three tasks. (1) For morphological construction, participants were required to create a concept based on a sentence that prompted how the morphemes should be combined without time limit. A sample question was ‘If one describes a flower that is big and red as “big red flower”, then how should one describe a flower that is big and purple?’ The expected answer is ‘big purple flower’. The accuracy of this task was used as the dependent measure. (2) For morpheme combination judgment, participants were required to identify a concept with appropriately combined morphemes without time limit. A sample question would be “how should we describe flowers that grow on a tree? (A) tree-flower; (B) flower-tree”. The letters ‘A’ and ‘B’ were presented in grey on the screen, and became black when the corresponding option was read aloud. Participants were required to click on either ‘A’ or ‘B’. (3) For homophone morpheme verification, participants listened to three two-character words and saw the corresponding grey letters ‘A’, ‘B’ and ‘C’ turned black. These three words carried a common homophone, in which two of the homophones shared a common meaning while the third one was distinctive in meaning. Participants were required to select the word with a homophone with distinctive meaning by clicking either ‘A’, ‘B’ or ‘C’ without time limit. For tasks (2) and (3), the corrected accuracy was used as the dependent measure.

8. Non-verbal intelligence. Non-verbal intelligence was measured by Raven’s Standard Progressive Matrices during the pretest only. In this test, each item consisted of a visual geometric pattern with a missing part. Participants were required to select an image that best completed the pattern out of six to eight alternatives. Scoring procedures will be based on the local norm established by the Hong Kong Education Department in 1986

(g) Data collection and analysis

There were two phases of data collection. Phase 1 was conducted in Jan 2019 to Aug 2019 to try out the training and testing protocol while the full set of training games were being developed. Phase 2 was conducted in Jan 2020 as a full implemention of the data collection for the project.

Phase 1 Data Collection

Phase 1 involved 2 primary schools (Po Leung Kuk Riverain Primary School and Toi Shan Association Primary School). We recruited 21 primary school students with dyslexia, 19 of which completed 20 hours of perceptual training, one hour per day, as a type of after-school activity, and their Chinese reading and other cognitive performance was measured before and after training to assess the effectiveness of perceptual training to improving Chinese reading performance.

Study Design

We adopted a randomized-controlled trial design, in which students were assigned to two groups, the control group and the treatment group (Figure 6). All students participated in the three-month training at the same time at school, and completed a prepost test before and after training to capture the amount of behavioural changes induced by the training. In addition, the control group performed a prepost test about a month before the training so as to capture the amount of behavioural changes that might naturally occur without any training, such as that induced by schooling and maturation. The treatment group also performed an additional test about a month after the training to examine whether the training-induced changes, if any, was sustained for a month.

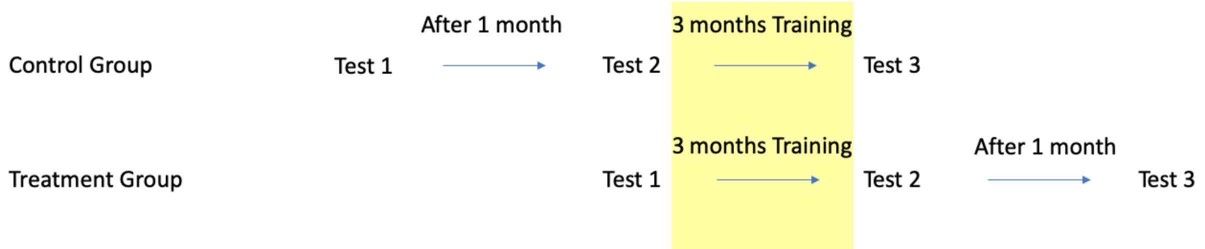

Figure 6. The design of the study in Phase 1 data collection.

In this design, the critical comparison is that the amount of behavioural changes between test 1 and test 2 for the treatment group should be statistically larger than that of the control group, which indicates that the amount of behavioural changes induced by the training is larger than that of any naturally-occurring changes. This provides evidence that the training is useful in improving behavioural performance of the students in the tested tasks.

Perceptual Training

In Phase 1, the mobile application was already developed on iOS, Android and website platforms with four games (Games 1-4).

<u>Phase 2 Data Collection</u>

Phase 2 was conducted in Jan 2020 and was the full implemention of the project. We recruited 4 primary schools (Ng Clan's Association Tai Pak Memorial School; Sacred Heart of Mary Catholic Primary School; Free Methodist Mei Lam Primary School; and Kowloon City Baptist Church Hay Nien (Yan Ping) Primary School) and recruited 73 primary students diagnosed with developmental dyslexia to join the project. Each school had a different training period within the spring semester according to the school schedule.

A similar randomized-controlled trial design as that in Phase 1 was adopted, with the exception that the no-training waiting time between test 1 and test 2 for the control group was increased to about 3-4 months. This made the control for natural improvements (e.g., that related to maturation and schooling) more complete than that of Phase 1. The prepost test in Phase 2 was identical to that of Phase 1.

Perceptual Training

In Phase 2, the mobile application was developed on iOS, Android and website platforms with all eight games.

The Impact of COVID-19

The compulsory school suspension in Feb 2020 caused an abrupt suspension of the data collection. Since all the laboratory at the university was forced to close, no testing could take place. Also, since all the primary schools had school suspension, the training was postponed. Until later when half-day primary school was resumed, it was still impossible for the training to resume because all the training sessions could only be scheduled in the afternoon, during which the schools have closed down already.

In July 2020, the university laboratory was allowed to reopen with specific condition and with strict hygienic procedure, and therefore we had seriously considered resuming the project by moving the training online. However, there were several important considerations: (1) it was too big of a time gap between the testing and training performed in January such that the whole testing procedure had to be restarted if data collection was resumed; (2) We did not know about the development of the pandemic which determined how long we could keep the laboratory open; and (3) we did not have sufficient time and manpower to restart the whole data collection, which spanned through 8 months based on our experience in 2019, data collection for a large-scale training study as the current one was considered impossible. And it turned out that there was another phase of pandemic in July that the laboratory was closed after re-opening for merely two weeks.

As a result, we discontinued the data collection since the end of January, 2020. In January, only one primary school started the training, involving 14 students. In total 46 students participated in test 1, or both test 1 and test 2.

Analysis

For data analyses, 1-2 participants in some of the tasks were excluded from data analyses because of equipment failure in audio recording.

For all cognitive measures, a composite score was calculated to summarize the dependent measure of the three tasks underlying each measure. For each construct, each of the three dependent measures was scaled to a range of 0 to 1 when appropriate, and then an average of was taken from the three measures to derive the composite score.

For each construct, we performed a Group (Treatment / Control) x Testing (Test 1 / Test 2) ANOVA to examine if the amount of behavioural changes induced by the training is larger than that of any naturally-occurring changes.

Since Phase 2 data collection was stopped because of COVID 19, the data analysis was conducted only for the data collected during Phase 1.

(h) Results and Discussion

Training Results

Phase 1 Data Collection

For the perceptual training, participants finished 20 hours of training, and made significant progress in the training (Table 1). The individual difference in the training progress was huge. Some had completed about 60% of the levels even for the advanced set (e.g., Participant 48), while others only finished 27% of the levels for the fundamental set (e.g., Participant 33). The highly varied progress indicates the importance of individualizing the training of children with dyslexia.

	Set 1 (Fundamental)				Set 2 (Advanced)			
Participant	Game 1	Game 2	Game 3	Game 4	Game 1	Game 2	Game 3	Game 4
27	23	56	20	10				
28	43	77	60	22				
30	29	77	60	20				
31	54	75	42	17				
32	98	77	60	31	21	33	46	9
33	18	36	10	11				
34	62	74	60	22				
36	55	73	56	32				
37	87	75	59	31				
38	41	77	37	29				
39	83	77	59	31				
40	100	77	60	32	2	37	49	5
41	50	77	55	29				
44	35	77	59	9				
45	99	77	56	31	7	29	4	1
47	97	77	59	23				
48	99	77	59	31	29	61	52	14
49	53	77	56	25				
54	98	77	53	31	5	44	46	2
69	75	76	60	29				
Total Levels	100	77	60	32	80	100	60	24

Table 1. The highest level passed by each participant for the perceptual training in Phase 1 data collection.

For the face-to-face RAN training, given that roughly half of the students with Chinese dyslexia showed deficits in RAN, we further divided the students into two groups by median split based on their RAN performance in the first session. The initially-slower group were likely to be those who suffered from RAN deficit, while the initially-faster group did not.

We observed a significant interaction between Group (initially-faster / initially-slower) and Training Session (first session / last session) on response time per digit, $F(1,17) = 5.08$. p

= .038, in which the response time per digit improved after training for both groups, with a larger degree of improvement for the initially-slow group than the initially-fast group (Figure 7).

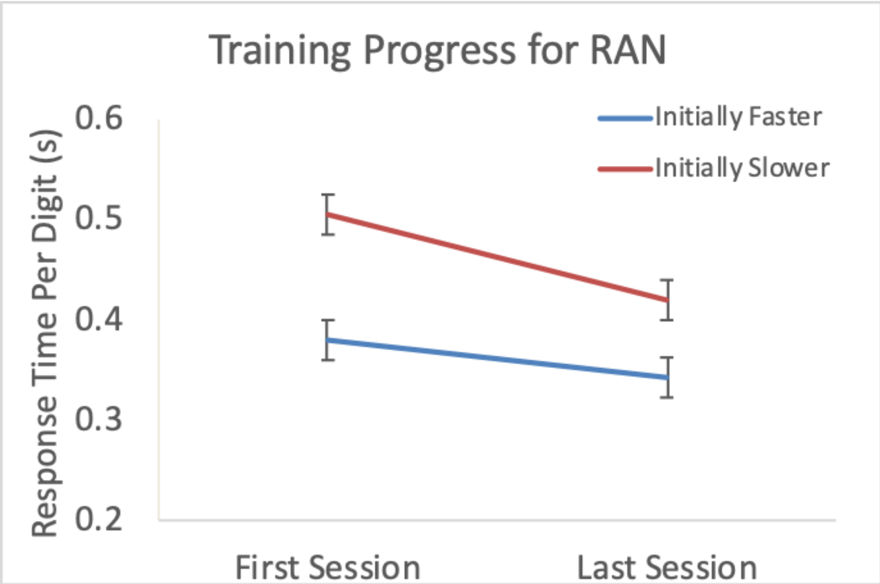

Figure 7. The training progress of the RAN task in Phase 1 data collection.

Prepost Tests

For non-speeded reading, the Group (Treatment / Control) x Testing (Test 1 / Test 2) ANOVA on word reading accuracy with trained characters revealed a significant Group x Testing interaction, $F(1,15) = 8.46$, $p = .01$, suggesting that improvement in word reading performance was larger in the treatment group than that of the control group (Figure 8). This effect generalized to untrained transfer characters, $F(1,15) = 6.08$, $p = .026$, with a similar pattern of effects (Figure 8). For speeded reading task, the Group x Testing interaction did not reach significance ($F < 1$; Figure 9).

For the other cognitive constructs, the Group x Testing interaction reached significance only for morphological awareness, $F(1,17) = 7.52$. $p = .014$, in which the improvement in morphological awareness was larger in the treatment group compared with that of the control group. The interaction effect of other constructs did not reach significance ($ps > .13$).

In sum, the training significantly improved word reading performance, in particular, non-speeded reading task. The improvement was not specific to the characters that one learned during the training, but generalized to the untrained transfer characters, suggesting that the improvement was generally related to the underlying cognitive processes that support Chinese character reading. For the cognitive constructs, we probably had insufficient statistical power to reveal the effects since many of them did show trends of changes compatible with the predictions. An except is the morphological awareness construct that showed a significant interaction effect. Since the morphological awareness tasks tapped onto homophone judgments, which could partially replied on the audiovisual mapping between the same pronunciation and the specific visual form of the characters, morphological awareness might improve with improved perceptual representation of the characters.

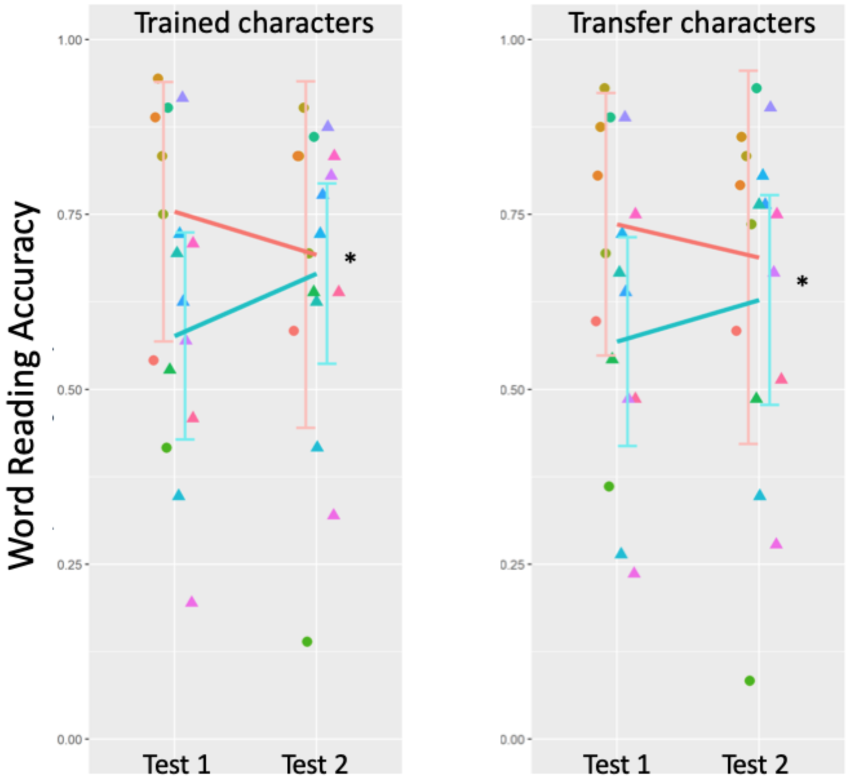

Figure 8. Word reading accuracy of the non-speeded reading task for the trained and transfer characters. The circles and the orange line indicate data of the control group, while the triangles and the blue line indicate data of the treatment group.

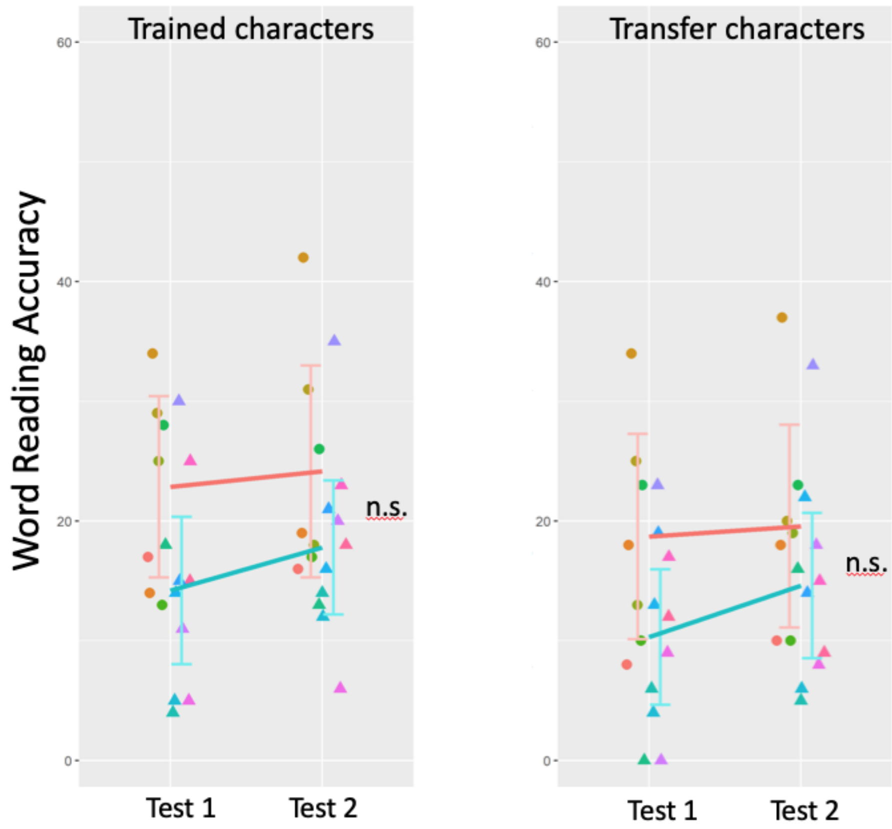

Figure 9. Word reading accuracy of the speeded reading task for the trained and transfer characters. The circles and the orange line indicate data of the control group, while the triangles and the blue line indicate data of the treatment group.

(i) Conclusions and Recommendations

Theoretical conclusion and recommendations

In contrast to some researchers' rejection of visual perception as a possible cause of developmental dyslexia (Ramus, 2003; Vellutino, 1979), the current findings highlight the effectiveness of perceptual training in improving Chinese word reading in children with developmental dyslexia. It echoes with the recently renewed interest in understanding the visual factors in developmental dyslexia (Stein & Kapoula, 2012), adding perceptual processes of words to the considerations of building a multifactorial model of developmental dyslexia (Hancock et al., 2017; Pennington, 2006; Perry et al., 2019; Peterson & Pennington, 2015). Practically, students with developmental dyslexia should consider using this app as an additional learning tool to complement the current intervention.

Project Management

Even though the project has been hit directly by COVID-19 such that the data collection in Phase 2 had been abruptly stopped, it was lucky that we pushed very hard to have a round of data collection just a few months after the start of the project such that we managed to collect useful data to test the hypothesis and complete the project objectives even with the pandemic. We had over-achieved by recruiting about 90 students (while the original plan was to recruit 36 as stated in the proposal). If the project were not affected by COVID-19, we would have one of the largest data sets for training studies for children with developmental dyslexia in the literature.

<u>Deliverable 1: Project Objectives</u>

We have achieved the project objectives with the following. First, the perceptual training has been shown to be able to effectively improve Chinese word reading performance of children with developmental dyslexia, in particular in the non-speeded reading task. Second, we had successfully developed a prototype of a mobile application that works on different platforms including websites, iOS and Android platforms. Third, our understanding of development of reading fluency has been enhanced by showing that perceptual training plays an important role in improving reading performance.

Deliverable 2: The mobile application

The mobile application has been uploaded to the PI's laboratory website for any users to download (https://sites.google.com/view/yettawong/publications). The design of the application is now tailor-made such that no 'user guide' is required anymore. Public users can directly registered their account with their personal email and start playing right away. The application also includes a general video to introduce the game design, and has a separate instruction video for each game. This makes the app user friendly, which has been confirmed during the Phase 2 data collection, in which students simply downloaded the app and started using it by themselves without any further instruction from the experimenters.

Deliverable 3: Dissemination seminar

A dissemination seminar was held in Dec 2019 in the Learning & Teaching Expo 2019, a large-scale exhibition participated by parents, teachers and researchers, to explain the initial findings of the Phase 1 data collection of this project. Teachers expressed their eagerness to use this mobile training to help their students, and SEN coordinators of some schools also expressed interest in further collaborations based on this project.

The information of the seminar could be found here:

https://lte2019.sched.com/speaker/dr_yetta_wong_kwai_ling_zao_zhen_.203by26d

The PDF of the seminar has been uploaded to HKEdCity:

https://www.hkedcity.net/cms_files/cms-sen/1-1000/716e7d6c96bafeb1f6a38fdd2b195b85902/Wong_L&TExpo_v2_public.pdf

The recorded video of the talk can be found here:

https://www.hkedcity.net/sen/spld/subject/page_5e466195903443a82c3c9869

The abstract of this seminar is attached below for reference.

The use of mobile application to improve Chinese reading performance in children with dyslexia

透過流動應用程式改善讀寫障礙兒童的中文閱讀表現

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Children with dyslexia face huge difficulty learning to read. It is known to be a complex disorder involving neural, cognitive and genetic factors. While many intervention strategies have been developed, few have been demonstrated to be useful for improving reading performance. Our team will share our on-going project that explores an innovative intervention strategy – perceptual training in a gamified, individualized, computerized and mobile context. The speaker will share our recently developed mobile application that assists children to develop various perceptual skills, which aims to relax the perceptual bottlenecks of reading development. The speaker will also discuss the effectiveness of this intervention programs, and how perceptual training can be a promising intervention strategy that is cost-effective, accessible, fun, and catering for the diversified needs of individual learners.

(150 words max)

患讀寫障礙的兒童學習閱讀時會遇到莫大困難。此學習障礙成因複雜，已知涉及大腦神經、認知和遺傳等因素。雖然介入策略很多，僅有小部份獲證實能改善閱讀表現。本研究團隊正研究一項創新的讀寫障礙介入策略 - 透過遊戲化、個人化、電腦化及流動的環境提供感知訓練。最近由團隊開發的應用程式，以發展感知技巧，從而紓緩閱讀發展的樽頸為目的。講者會討論此介入方案的成效，和探討感知訓練如何成為一套兼具成本效益、娛樂性、容易接觸以及照顧個人差異的介入策略。

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