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Research Article

Development of the English Listening and Reading Computerized Revised Token Test Into Cantonese: Validity, Reliability, and Sensitivity/Specificity in People With Aphasia and Healthy Controls

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Purpose: This study reports the psychometric development of the Cantonese versions of the English Computerized Revised Token Test (CRTT) for persons with aphasia (PWAs) and healthy controls (HCs).
Method: The English CRTT was translated into standard Chinese for the Reading–Word Fade version (CRTT-R-$_{WF}$-Cantonese) and into formal Cantonese for the Listening version (CRTT-L-Cantonese). Thirty-two adult native Cantonese PWAs and 42 HCs were tested on both versions of CRTT-Cantonese tests and on the Cantonese Aphasia Battery to measure the construct and concurrent validity of CRTT-Cantonese tests. The HCs were retested on both versions of the CRTT-Cantonese tests, whereas the PWAs were randomly assigned for retesting on either version to measure the test–retest reliability.
Results: A two-way, Group × Modality, repeated-measures analysis of variance revealed significantly lower scores for the PWA group than the HC group for both reading and listening. Other comparisons were not significant. A high and significant correlation was found between the CRTT-R-$_{WF}$-Cantonese and the CRTT-L-Cantonese in PWAs, and 87% of the PWAs showed nonsignificantly different performance across the CRTT-Cantonese tests based on the Revised Standardized Difference Test. The CRTT-R-$_{WF}$-Cantonese provided better aphasia diagnostic sensitivity (100%) and specificity (83.30%) values than the CRTT-L-Cantonese. Pearson correlation coefficients revealed significant moderate correlations between the Cantonese Aphasia Battery scores and the CRTT-Cantonese tests in PWAs, supporting adequate concurrent validity. Intraclass correlation coefficient showed high test–retest reliability (between .82 and .96, $p < .001$) for both CRTT-Cantonese tests for both groups.
Conclusions: Results support that the validly translated CRTT-R-$_{WF}$-Cantonese and CRTT-L-Cantonese tests significantly differentiate the reading and listening comprehension of PWAs from HCs and provides acceptable concurrent validity and high test–retest reliability for both tests. Furthermore, favorable PWA versus HC sensitivity and specificity cutoff scores are presented for both CRTT-Cantonese listening and reading tests.

Aphasia is an acquired neurogenic impairment of language that crosses input and output modalities and language domains resulting in difficulties using linguistic symbols while listening, reading, speaking, and writing (McNeil & Pratt, 2001). Aphasia also excludes sensory, motor, psychiatric, and primary cognitive deficits, although these deficits frequently accompany aphasia. According to the Department of Health, there are about 25,000 new cases of stroke each year in Hong Kong, with between 17% and 38% of the survivors having persistent language impairments at various levels of aphasia severity in Cantonese (Kong, 2011).

Cantonese is a language spoken by over 70 million people (Eberhard et al., 2019) and is the official language of Hong Kong and Macau. Apart from Hong Kong, Macau, and southern China, Cantonese is also widely spoken by Chinese in Southeast Asia, Europe, and North America. The use of Cantonese varies depending on context and modality.

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In terms of speaking, colloquial Cantonese is used in casual situations such as daily conversation, and it contains many colloquial lexical items that, when transcribed into written format, cannot be read out fluently in Mandarin (also known as the "standard Chinese"). Formal Cantonese is used in formal occasions such as radio broadcast and news reporting. The transcription of formal Cantonese can be read out fluently in Mandarin after replacing the Cantonese function words with their counterparts in standard Chinese (Yeung et al., 2008). Colloquial Cantonese does exist in writing, known as "written Cantonese" (Bauer, 1988); however, it is not used in official written documents and published materials. Standard Chinese is the written form that has been used in the Hong Kong educational system from primary school to tertiary education and in official documents (Yeung et al., 2008). In terms of scripts, both formal Cantonese and standard Chinese are written using the traditional scripts/characters. Even though Cantonese shares a similar writing system with Mandarin, it differs substantially from Mandarin in terms of phonology, lexical tones, and some grammatical structures. Therefore, development of a language assessment test in one language cannot be simply applied to the other.

Despite the relatively large number of Cantonese speakers around the world, the only standardized assessment available for aphasia is the Cantonese Aphasia Battery (CAB; Yiu, 1992). This test was adapted from the Western Aphasia Battery (Kertesz, 1982), with some adjustment for linguistic and cultural appropriateness. The CAB provides subtests for different input and output modalities, including speaking, listening, reading, and writing. It adopts the diagnostic criteria of Aphasia Quotient (AQ) and subtypes from the Western Aphasia Battery by measuring the scores in spontaneous speech (fluency and content), confrontation naming, repetition, and auditory comprehension. The test computes quotients for different verbal subtests but does not provide further explanation of the reading and writing subtest scores. In addition, the test was developed in 1992, and there has been no updated version for more than 25 years despite cultural and linguistic changes. Some of the stimuli included in the listening and reading tasks are not familiar in current daily communication. For instance, the reading stimuli included outdated information about Hong Kong colonial history and world energy. The stimuli used within the auditory comprehension tasks and across the auditory and reading comprehension tasks are not adequately matched and differ in terms of their linguistic features, such as sentence length, syntactic structure, semantic and lexical items, and response mode. These differences make it difficult to compare performance within and between the auditory and reading modalities, and limited sampling for each component compounds this difficulty. Therefore, performance on these tests may be influenced not only by the severity of the language impairment or the degree of language competence but also by other factors such as their premorbid knowledge and their familiarity with specific lexical items or commands within the tests.

Computerized Revised Token Test

Current standardized tests for aphasia have difficulties making comparisons between listening and reading comprehension due to stimulus factors that fail to match for lexical-semantic and syntactic structures, comparability of test stimuli, scoring criteria, and response requirements. The Computerized Revised Token Test (CRTT) is a computerized and revised version of a token test first conceptualized by DeRenzi and Vignolo (1962). The test stimuli are well controlled in terms of syntactic structures and linguistic units. The target lexical items are composed of five colors, two shapes, and two sizes, which are considered as universal concepts that can minimize the effect of linguistics or cultural differences due to client's personal background and lifetime experiences (McNeil et al., 2015). Moreover, the test has a systematic design for sentence types and length, which can reflect the client's severity of impairment from the sentence level of linguistics complexity using a multidimensional scoring system. Since the stimuli in listening and reading comprehension versions of the CRTT are consistent, the results across the two tests are comparable save for the stimulus modality. Furthermore, McNeil et al. (2015) found that the performance of persons with aphasia (PWAs) were highly correlated between the listening comprehension version of CRTT (CRTT-L) and three reading versions of the test (CRTT-R; i.e., Computerized Revised Token Test–Reading–Full Sentence, Computerized Revised Token Test–Reading–Word Constant, and Computerized Revised Token Test–Reading–Word Fade [CRTT-R-$_{WF}$]), thus reflecting similar linguistic processing difficulties across presentation formats in PWA. It is suggested that CRTT-R-$_{WF}$ is preferred over the other CRTT-R versions (i.e., CRTT-R-Word Constant and CRTT-R-Full Sentence), as CRTT-R-$_{WF}$ can capture the word-by-word reading time of the subjects and calculate the reading time across different lexical items, commands, and subtests (McNeil et al., 2015). Furthermore, the presentation of stimuli in CRTT-R-$_{WF}$ simulate better the serial word presentation of the listening version of CRTT (i.e., CRTT-L) than other CRTT-R versions, which allows for a more cognitively comparable cross-modality comparison of language comprehension. Overall, the CRTT has been demonstrated to have high construct and concurrent validity and test–retest reliability to measure sentence comprehension in PWA (McNeil et al., 2015).

The Revised Token Test (McNeil & Prescott, 1978) and its computerized version (CRTT) has been adapted for assessment of language comprehension in different languages, including Turkish (Turkyilmaz & Belgin, 2012), Spanish (Gallardo et al., 2011; Quintana et al., 2015), Mandarin Chinese (CRTT-Mandarin; Chen et al., 2013), and several others currently in development. The CRTT-Mandarin was found to show acceptable concurrent validity in terms of the correlation with the overall score of the Concise Chinese Aphasia Test (Chung et al., 2003; $r = .75$), which is a standardized assessment test for PWAs in Taiwan (Chen et al., 2013). Despite the relatively small sample size, the study marks an important milestone in developing a valid and standardized test for Mandarin-speaking PWAs. Since the Revised Token Test is unbiased in terms of gender, educational, and premorbid language level (McNeil & Prescott, 1978) and the CRTT has been tested on Taiwanese Mandarin speakers, with further development the CRTT-Mandarin might provide a useful assessment tool for Mandarin speakers in mainland China.[1]

As Cantonese is extensively different from Mandarin and considering the limited standardized aphasia tests available in Cantonese, this study sought to develop the Cantonese reading (CRTT-R-$_{WF}$-Cantonese) and listening (CRTT-L-Cantonese) versions of CRTT for assessment of language comprehension in PWA. Although Cantonese spoken outside Hong Kong may be slightly different from Hong Kong Cantonese in terms of some vocabulary items used due to the different sociopolitical systems, they share substantially the same phonological system and can be easily understood. Therefore, it is believed that the Cantonese version of CRTT should be applicable to the larger global population of Cantonese speakers living outside Hong Kong.

Research Aims Assessed

This study aims to report (a) the translation procedures of the CRTT-English into the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese; (b) the construct validity of the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese; (c) individual differences between the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese; (d) the sensitivity, specificity, and cutoff scores for the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese; (e) the intermodality associations between the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese; (f) the concurrent validity of the CRTT-Cantonese tests as compared to the CAB; and (g) the test–retest reliability for the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese tests among PWAs and healthy controls (HCs).

Method

Development of CRTT-Cantonese

Translation procedure. The English CRTT was initially translated into formal Cantonese (forward translation) by two independent translators, including one native Cantonese student enrolled in the master of speech therapy (MST) program and one professional Cantonese–English translator. Then, a panel consisting of the first author and four native Cantonese speakers, including the professional translator, one speech therapy professor, and two new MST students, discussed and compared the two independent translations. In order to ensure the CRTT-Cantonese appears culturally appropriate and linguistically natural for both listening and reading comprehension, the panel suggested the necessary adjustments to adapt the CRTT-L into formal Cantonese and the CRTT-R-$_{WF}$ into standard Chinese, both using the traditional scripts. The panel also suggested seven changes on word choices such as translating “touch” as 指出 instead of 指 and “circle” as 圓圈 instead of 圓形. The syntactic structures of the sentences are typically similar across the listening and reading versions of CRTT-Cantonese, with some difference in terms of the lexical items. For instance, the word “little” is translated as [sɐi33] in CRTR-L-Cantonese and as 小 [siu35] in CRTT-R-$_{WF}$-Cantonese. Although 小 can also be read aloud as [siu35], it is unnatural to use it in the spoken language to represent the meaning of “little” (refer to Table 1).

Subsequently, the professional translator provided the second versions of CRTT-Cantonese for listening (CRTT-L-Cantonese) and reading (CRTT-R-$_{WF}$-Cantonese). The forward translations of CRTT tests (second version) were then translated back from Cantonese to English (backward translation) by two native Cantonese–speaking MST students who were not among the forward translation panel. The backward translations of CRTT were sent back to the test developer for comments and final approval. The backward translations were judged to be appropriate translations both in comparability of language and similarity of interpretation. Hence, no further changes were made to the second (and final) versions of CRTT-Cantonese. Five native Cantonese speakers also confirmed that the final versions of the translations were natural and did not include any orthographic errors. It is notable that differences between the lexical items in reading and listening versions is limited. Overall, among the 1,493 morphemes presented in CRTT-Cantonese tests, 281 (18.80%) morphemes were different between the two versions, while 1,212 (81.20%) morphemes were the same across the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese. Table 1 displays a summary of differences in lexical items used in the CRTT-Cantonese tests and the CRTT-Mandarin and shows an example of comparisons between the CRTT-Cantonese tests. Detailed comparisons are displayed in the Appendix.

Participants

The PWA participants were recruited through poster presentations at different institutions such as community centers and support groups for PWAs. The matched HC group was recruited from promotions at elderly community groups, The Hong Kong Polytechnic University campus, and social media. A survey was provided to all participants (or caregivers if necessary) to collect demographic information and medical history. The inclusion criteria for all the participants were as follows: (a) native Cantonese speakers with a minimum level of elementary education (6 years or above); (b) had no history of speech, language, cognitive, and/or psychiatric deficits; (c) visual acuity higher that 20/40 (based on Snellen chart or Near Vision Test); (d) a pure-tone hearing threshold lower than 50 dB HL at 500, 1000, 2000, and 4000Hz in both ears; (e) without major cognitive impairments (except for language impairment in the PWA group) as determined using the Hong Kong version of the

[1]Dr. Min Zhang is currently developing another version of the Mandarin CRTT (called: CRTT-R-$_{WF}$ and CRTT-L-Mandarin Mainland), which includes different recorded auditory stimuli without a Taiwanese accent.

Table 1. Summary of differences in lexical items used in the Cantonese Computerized Revised Token Test Listening (CRTT-L-Cantonese) and Reading–Word Fade (CRTT-R-$_{WF}$-Cantonese) subtests and the Mandarin Computerized Revised Token Test (CRTT-Mandarin), illustrated with sample sentences.

English CRTT	"possessive"	little	and	by the	instead of	instead of
CRTT-L-Cantonese	嘅 [kɛ33]	細 [sɐi33]	同埋 [tʰʊŋ21] [mai21]	喺…側邊 [hɐi35]…[tsɐk̚55] [pin55]	唔好…而係 [m̩21] [hou35] [ji21] [hɐi22]	而唔係 [ji21] [m̩21] [hɐi22]
CRTT-R-$_{WF}$-Cantonese	的 [tik55]	小 [siu35]	和 [wɔ21]	在…旁邊 [tsɔi22]…[pʰɔŋ21] [pin55]	不要…而是 [pɐt̚55] [jiu33] [ji21] [si22]	而不是 [ji21] [pɐt̚55] [si22]
CRTT-Mandarin	的 [tɤ55]	小 [ɕjɑʊ214]	和 [xɤ35]	在…旁边 [tsaɪ51]…[pʰɑŋ35] [pjɛn55]	不要…而是 [pu35] [jɑʊ51] [ə˞35] [ʂʅ51]	而不是 [ə˞35] [pu35] [ʂʅ51]

English CRTT	Touch	the	little	blue	square	and	the	big	black	square	.
POS	*Verb*	*Article*	*Adjective*	*Adjective*	*Noun*	*Conjunction*	*Article*	*Adjective*	*Adjective*	*Noun*	
CRTT-L-Cantonese	指出	細	嘅	藍色	正方形	同埋	大	嘅	黑色	正方形	。
CRTT-R-$_{WF}$-Cantonese	指出	小	的	藍色	正方形	和	大	的	黑色	正方形	。
POS	*Verb*	*Adjective*	*Particle*	*Adjective*	*Noun*	*Conjunction*	*Adjective*	*Particle*	*Adjective*	*Noun*	

Note. The choice of translation for "instead of" was dependent on the sentence structure. POS = Part of speech.

Oxford Cognitive Screen (HK-OCS; Kong et al., 2016); and (f) possessed the necessary lexical knowledge, perceptual abilities (i.e., shape, size, color), and sufficient hand motor abilities to execute the CRTT tasks as determined by their performance during the CRTT-R-$_{WF}$-Cantonese and CRTT-L-Cantonese pretests. Additionally, any PWAs with a poststroke onset time of less than 4 months and/or a diagnosis of global aphasia based on the CAB were also excluded from the study.

A total of 74 participants; 42 HCs and 32 PWAs who met the inclusion criteria, participated in this study. The age, gender, and education level of HCs were distributionally matched with the PWAs. The demographic details of the participants and further clinical information, including poststroke onset, aphasia type, and CAB scores, are provided in Table 2. The PWA group (22 men and 10 women) had a mean age of 58.69 years (range: 46–72 years, SD = 6.25) and a mean education level of 11.69 years (range: 6–19 years, SD = 3.75). All of the PWAs were premorbidly right-handed with a single left hemisphere stroke with an average poststroke onset of 62.16 months (range: 4–194 months, SD = 45.4). The mean overall AQ score from the CAB for the PWA group was 82.61 (range: 49.80–95.40, SD = 10.11), with a mean score of 8.82 (range: 4.90–10.00, SD = 1.14) for auditory comprehension and a mean raw score of 64.47 (range: 44–76, SD = 10.14) for reading comprehension. The HC group (28 men and 14 women) had a mean age of 58.65 years (range: 43–76 years, SD = 7.94) and a mean education level of 11.90 years (range: 6–19 years, SD = 3.15). The mean overall AQ score for CAB for the HC group was 99.50 (range: 97.80–100.00, SD = 0.63), with a mean subtest score of 9.92 (range: 9.10–10.00, SD = 0.16) for auditory comprehension and a mean raw score of 75.12 (range: 68–76, SD = 1.64) for reading. The study was approved by the Human Subjects Ethics Committee of The Hong Kong Polytechnic University, and written consents were obtained from the participants before the commencement of the study. The participants were reimbursed for their travel expenses, which was supported by the Dean Reserve Fund granted by The Hong Kong Polytechnic University.

Stimuli

Stimuli for the CRTT-L-Cantonese was recorded in a sound-attenuated booth using a Telefunken M80 dynamic microphone connected to a Focusrite Scarlett 2i2 USB audio interface. The bit rate was 128 kpbs, and the sampling frequency was 44.1 kHz. The distance between the microphone and the speaker was approximately 6 in. The auditory stimuli were recorded in natural voice quality by a male native Cantonese speaker (among six other male candidates), who received the highest perceptual rating from five native Cantonese speakers in terms of speech rate, pitch range, clarity, and voice quality. The speech rate was controlled at an average rate of approximately four syllables per second, without any unusual emphasis (rate, pitch, or intensity) on any constituents in the sentence (Chan & Lee, 2005; McNeil et al., 2015). During the recording process, a native Cantonese–speaking student studying MST monitored the recording through headphone AKG K77. Immediate feedback was given when any articulation or prosodic errors were noticed. Each stimulus was recorded for three trials consecutively and was perceptually judged by three native Cantonese speakers for speech rate, intensity, vocal quality, and clarity. The stimulus was re-recorded until at least one trial of the stimulus was agreed among three judges to be acceptable. All audio files were then edited using Praat to achieve an average intensity of 70 dB SPL, and 50 ms of silence was considered as a buffer between the beginning and at the end of the recording.

The lexical items for the CRTT-R-$_{WF}$-Cantonese stimuli were coded based on their part of speech and their words boundaries to ensure that the presentation method would be the same as the English CRTT-R-$_{WF}$ version (McNeil et al., 2015). All reading stimuli were entered into the program and presented in word-by-word self-paced

Table 2. Demographic details and clinical information of the participants based on the Cantonese Aphasia Battery (CAB).

Participants	Age	Gender	Education	TPO (months)	CAB_L	CAB_R	CAB_AQ	Aphasia type
HC01	56	F	11	—	9.95	76.00	99.70	None
HC02	59	M	9	—	9.70	76.00	99.40	None
HC03	61	F	11	—	10.00	76.00	100.0	None
HC04	49	M	11	—	10.00	76.00	100.0	None
HC05	53	M	11	—	9.70	74.00	98.80	None
HC06	58	M	11	—	10.00	76.00	100.0	None
HC07	68	M	11	—	10.00	76.00	100.0	None
HC08	63	M	11	—	10.00	76.00	100.0	None
HC09	63	F	7	—	10.00	76.00	99.80	None
HC10	69	M	8	—	10.00	76.00	99.60	None
HC11	68	M	9	—	10.00	76.00	99.20	None
HC12	62	M	11	—	10.00	74.00	99.0	None
HC13	65	M	7	—	9.10	74.00	97.80	None
HC14	55	M	8	—	10.00	74.00	97.80	None
HC15	58	M	15	—	9.70	76.00	98.80	None
HC16	54	M	16	—	10.00	76.00	100.0	None
HC17	53	M	11	—	9.85	74.00	99.50	None
HC18	55	F	16	—	10.00	76.00	100.0	None
HC19	66	F	11	—	10.00	76.00	100.0	None
HC20	62	M	18	—	10.00	76.00	100.0	None
HC21	64	F	6	—	10.00	75.00	100.0	None
HC22	59	M	12	—	10.00	76.00	100.0	None
HC23	60	F	11	—	10.00	76.00	100.0	None
HC24	60	M	12	—	10.00	76.00	99.40	None
HC25	50	M	14	—	9.70	74.00	99.00	None
HC26	50	F	12	—	9.85	76.00	99.50	None
HC27	68	M	9	—	10.00	76.00	100.00	None
HC28	47	M	14	—	10.00	76.00	100.00	None
HC329	74	F	12	—	10.00	68.00	98.10	None
HC30	71	M	8	—	9.85	76.00	99.30	None
HC31	48	F	14	—	9.75	74.00	99.50	None
HC32	62	M	62	—	9.80	70.00	99.00	None
HC33	50	M	14	—	10.00	74.00	100.00	None
HC34	76	F	8	—	9.95	75.00	98.50	None
HC35	52	F	19	—	10.00	76.00	100.0	None
HC36	65	F	14	—	10.00	74.00	98.80	None
HC37	63	M	12	—	9.87	74.00	99.70	None
HC38	43	M	14	—	10.00	75.00	99.00	None
HC39	48	M	20	—	10.00	76.00	100.00	None
HC40	47	F	16	—	9.85	76.00	99.70	None
HC41	55	M	11	—	10.00	76.00	100.00	None
HC42	54	M	13	—	10.00	76.00	100.00	None
PWA01	55	F	9	37	9.40	57.00	82.60	Anomic
PWA02	60	M	6	64	9.60	69.00	93.60	Unspecified
PWA03	58	F	12	31	8.85	76.00	93.10	Anomic
PWA04	46	M	11	121	4.90	44.00	49.80	Broca
PWA05	50	M	9	61	8.90	56.00	77.60	Conduction
PWA06	56	M	9	18	10.00	74.00	78.40	Anomic
PWA07	66	M	9	10	8.80	61.00	81.40	Anomic
PWA08	63	M	9	32	8.05	76.00	78.90	Anomic
PWA09	62	F	6	194	9.60	76.00	90.60	Anomic
PWA10	72	M	6	19	7.70	54.00	77.40	Anomic
PWA11	69	M	11	68	10.00	76.00	94.60	Unspecified
PWA12	59	M	9	29	9.70	76.00	92.00	Unspecified
PWA13	63	M	9	81	8.35	52.00	81.10	Anomic
PWA14	58	M	8	61	9.05	61.00	91.20	Anomic
PWA15	59	M	15	25	7.90	45.00	70.80	TM
PWA16	58	F	15	38	9.85	72.00	94.10	Anomic
PWA17	55	M	11	79	9.80	74.00	92.60	Anomic
PWA18	58	M	19	111	8.90	60.00	76.20	Anomic
PWA19	63	M	12	157	9.60	67.00	83.80	Anomic
PWA20	53	M	15	92	9.45	72.00	91.10	Anomic
PWA21	52	M	19	131	9.15	64.00	79.70	Anomic
PWA22	53	F	14	38	8.30	46.00	75.20	Anomic
PWA23	58	F	12	14	7.85	65.00	86.90	Anomic
PWA24	66	F	10	54	9.85	69.00	74.50	Conduction

(*table continues*)

Table 2. *(Continued).*

Participants	Age	Gender	Education	TPO (months)	CAB_L	CAB_R	CAB_AQ	Aphasia type
PWA25	62	M	18	38	7.40	46.00	63.20	TM
PWA26	50	F	15	75	9.25	72.00	88.70	Anomic
PWA27	52	M	18	33	6.10	62.00	82.60	TS
PWA28	67	M	12	92	8.90	62.00	82.00	Anomic
PWA29	70	F	6	6	9.80	66.00	90.80	Anomic
PWA30	52	F	14	85	9.30	76.00	95.40	Anomic
PWA31	55	M	15	91	8.45	72.00	71.30	TM
PWA32	61	M	12	4	9.50	65.00	82.20	Anomic

Note. Em dashes indicate data not available. TPO = time postonset; CAB_L = CAB Listening subtest; CAB_R = CAB Reading subtest; CAB_AQ = CAB Aphasia Quotient subtest; HC = healthy control; F = female; M = male; PWA = person with aphasia; TM = transcortical motor aphasia; TS = transcortical sensory aphasia.

manner, which simulated the processing in the CRTT-L (McNeil et al., 2015).

Procedure

The experiment was conducted over four sessions for the PWA group and three sessions for the HC group, including the implementation of all screening tests (i.e., visual and auditory screenings, HK-OCS, CAB, and CRTT-Cantonese pretests) and the experimental CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese tests and retests. There was a time interval of 5–12 days between the experimental CRTT-Cantonese tests and 7–21 days between the last CRTT-Cantonese test and retest, which was judged to be long enough to minimize practice effects and short enough to minimize the occurrence of an additional neurological event. The order of tests was counterbalanced among the participants in which half of the participants started with the CRTT-L-Cantonese followed by the CRTT-R-$_{WF}$-Cantonese in the next session or vice versa. Following the completion of the experimental tests, the retest session was arranged for PWAs at the fourth session and for the HCs at the third session. Since PWA participants were not able to complete both CRTT-Cantonese tests in the retest session, they were randomly assigned to retake either the CRTT-L-Cantonese or the CRTT-R-$_{WF}$-Cantonese, while HC participants completed both CRTT Cantonese tests in the third (i.e., retest) session. Only one HC was unable to complete the retest due to a schedule conflict.

The CRTT-Cantonese was administered using a laptop computer with a 14-in. diagonal screen (Lenovo, ThinkPad TP470) connected to a standard mouse. The stimuli were presented to participants through the laptop speaker. The laptop computer was positioned on a computer stand to ensure that the monitor was located at the eye level with a 16-in. distance from the participant. The CRTT-R-$_{WF}$-Cantonese was presented in a self-paced word-fade manner in which each word appeared by a single mouse click from the left to the right side of the screen and then disappeared with the onset of the following word. This style of stimuli presentation is consistent with the English CRTT-R-$_{WF}$ presentation and suggested to be more similar to the CRTT-L (McNeil et al., 2015). The written stimuli were presented in 36-point Arial font within a textbox near the bottom of the screen. The PWA participants were asked to use their intact hand (left hand) to respond to the stimuli, and HC participants used their nondominant hand (i.e., left hand) as well to be comparable with response mode of the PWA group. The participants' performances on each word, sentence, and subtests were recorded by the CRTT-Cantonese program, and the overall and efficiency scores were automatically computed accordingly.

The CRTT-Cantonese provides two scales to measure language comprehension. The overall score is calculated from the average of the 15-point multidimensional scale assigned to each content word in the sentence across all 10 sentences from all 10 subtests. The maximum value for all linguistic item, sentence, subtest, and overall assigned scores for both scoring metrics is 15.00. Moreover, the CRTT-Cantonese provides efficiency scores, which reflect the accuracy results in relation to the response generation time. The efficiency score is calculated by "multiplying the [CRTT] scores by the ratio of length of time, in seconds, that it takes to complete the command to the maximum time allowed per command" (McNeil et al., 2015, online supplemental material, p. 12). Further details for calculation of the CRTT overall and efficiency scores were reported by McNeil et al. (2015) as an online supplemental material.

Data Analysis

Data analyses were conducted using SPSS 25. Independent-sample t test or Mann–Whitney U test (when these measures were not normally distributed) was used to compare the demographic data and screening tests between the groups. In order to explore any association between demographic data and clinical information (i.e., age, education, and time poststroke) and participants' performance on CRTT-Cantonese tests, Pearson correlation analysis was conducted. A two-way repeated-measures analysis of variance (ANOVA), with group (PWA and HC) as the between-subjects factor and CRTT-Cantonese tests (CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese) as the within-subject factor, was used to measure the overall accuracy and efficiency scores across the groups and tests to determine the construct validity. The individual differences in performance on the CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese tests were examined in PWAs using the Revised Standardized Difference Test (RSDT; Crawford & Garthwaite, 2005). The generated receiver operating characteristic (ROC) curve (Hajian-Tilaki, 2013) was used to determine the sensitivity, specificity, and cutoff scores of the CRTT-Cantonese tests. The intermodality association between the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese was measured by the Pearson correlation and regression analysis of different CRTT-Cantonese test scores. Pearson correlation coefficients were used to measure the correlation between the overall scores from CRTT-Cantonese tests and CAB scores to evaluate the concurrent validity of the CRTT-Cantonese. Lastly, intraclass correlation coefficient (ICC) was used to examine the test–retest reliability for the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese.

Results

There were no significant differences between groups in terms of age ($t = -0.02$, $p = .10$) or education level ($t = 0.27$, $p = .18$). The measures from CAB including the AQ scores ($U = 0$, $p < .001$), auditory comprehension ($U = 99.00$, $p < .001$), and reading subtest scores ($U = 195.00$, $p < .001$) confirmed significantly lower language performance for the PWA group than the HC group. Furthermore, both groups showed comparable cognitive performance across different subtests of HK-OCS, except for some language-related subtests such as sentence reading, number writing, and calculation (see Table 3). Pearson correlations between age, education, and CRTT-Cantonese tests scores were significant only for the HC group (age and CRTT-L-Cantonese: $r = -.58$, $p < .001$; age and CRTT-R-$_{WF}$-Cantonese: $r = -.65$, $p < .001$; education and CRTT-L-Cantonese: $r = .46$, $p < .01$; education and CRTT-R-$_{WF}$-Cantonese: $r = .61$, $p < .001$). No significant correlations between the variables were found for the PWA group (age and CRTT-L-Cantonese: $r = .34$, $p = .053$; age and CRTT-R-$_{WF}$-Cantonese: $r = .09$, $p = .61$; education and CRTT-L-Cantonese: $r = -.10$, $p = .57$; education and CRTT-R-$_{WF}$-Cantonese: $r = -.17$, $p = .35$). Furthermore, there was no significant correlation between time poststroke onset and CRTT-L-Cantonese ($r = .09$, $p = .62$) and CRTT-R-$_{WF}$-Cantonese ($r = .07$, $p = .71$).

Construct Validity

Descriptive results for the overall scores and efficiency scores of CRTT-Cantonese tests are provided in Table 4. Regarding the construct validity, results of the ANOVA on overall CRTT-Cantonese score revealed a significant main effect of groups, $F(1, 72) = 104.66$, $p < .001$, with the PWA group demonstrating lower overall accuracy than the HC group (see Table 4). There was no significant main effect of CRTT-Cantonese tests, $F(1, 72) = 0.44$, $p = .51$, and no significant interaction between groups and tests, $F(1, 72) = 0.043$, $p = .84$, indicating that both groups showed a similar pattern of performance between the tests. A similar pattern was also observed in the analysis of the CRTT-Cantonese efficiency score in which there was a significant main effect of group, $F(1, 72) = 97.78$, $p < .001$, with the PWA group demonstrating a lower performance than the HC group and no significant main effect of CRTT-Cantonese tests, $F(1, 72) = 0.003$, $p = .96$, and no significant interaction between groups and CRTT-Cantonese tests, $F(1, 72) = 0.08$, $p = .78$.

Following McNeil et al. (2015), the RSDT was used to further assess individual differences between listening and reading against group differences based on a 2-*SD* criterion (Crawford & Garthwaite, 2005). This test was originally developed to determine the presence of neuropsychological dissociations in single-case studies. It uses a *t* distribution rather than the standard normal distribution to estimate

Table 3. The descriptive results and group differences for the Hong Kong version of the Oxford Cognitive Screen (HK-OCS) subtest scores among person with aphasia (PWA) and healthy control (HC) participants.

	HC (n = 42)			PWA (n = 32)			
HK-OCS subtests	*M*	*SD*	Range	*M*	*SD*	Range	*p*
Picture Naming	3.90	0.37	2–4	3.69	0.64	2–4	.07
Semantics	2.98	0.15	2–3	2.94	0.44	2–3	.41
Sentence Reading	21.24	0.98	19–22	19.25	3.81	5–22	.003**
Orientation	4.00	0.00	4–4	3.94	0.25	3–4	.10
Verbal Memory	3.57	0.63	2–4	3.66	0.60	2–4	.51
Episodic Memory	3.88	0.33	3–4	3.69	0.54	2–4	.07
Visual Field Test	4.00	0.00	4–4	3.94	0.25	3–4	.10
Broken Hearts Test	48.38	1.87	44–50	48.09	2.01	43–50	.56
Executive Tasks: Task Switching	–0.64	1.54	–2–8	–0.44	1.39	–1–5	.19
Number Writing	2.83	0.38	2–3	2.06	1.11	0–3	.001***
Calculation	3.86	0.42	2–4	3.59	0.71	1–4	.04*
Gestural Imitation	11.43	1.11	8–12	10.97	1.77	3–12	.11

Note. Visual Field Test: While maintaining a central fixation, the participants need to indicate if they see hand movement. Broken Heart Test: The participants need to cross out all the complete hearts. Executive Tasks: Task Switching: The participants need to make connections from large to small and alternate between triangles with circles.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4. Descriptive data for the overall scores and efficiency scores of the Cantonese Computerized Revised Token Test Listening (CRTT-L-Cantonese) and Reading–Word Fade (CRTT-R-$_{WF}$-Cantonese) subtests across different groups.

Group	CRTT measure	*N*	*M*	*SD*	Range	Maximum test score
HC	Overall CRTT-L-Cantonese	42	13.70	0.51	12.43–14.62	15.00
	Overall CRTT-R-$_{WF}$-Cantonese	42	13.76	0.65	12.38–14.89	15.00
	Efficiency CRTT-L-Cantonese	42	12.51	0.65	11.32–13.99	15.00
	Efficiency CRTT-R-$_{WF}$-Cantonese	42	12.55	0.92	10.29–14.16	15.00
PWA	Overall CRTT-L-Cantonese	32	11.48	1.71	6.24–13.75	15.00
	Overall CRTT-R-$_{WF}$-Cantonese	32	11.60	1.22	8.36–13.10	15.00
	Efficiency CRTT-L-Cantonese	32	10.05	1.81	5.20–12.87	15.00
	Efficiency CRTT-R-$_{WF}$-Cantonese	32	9.99	1.57	4.92–12.05	15.00

Note. Efficiency scores are calculated "by multiplying CRTT score by the ratio of length of time, in seconds, that it takes to complete the command to the maximum time allowed per command" (McNeil et al., 2015, p. 12).

whether an individual score is significantly lower than the scores of the control sample (Crawford & Garthwaite, 2005; Crawford & Howell, 1998). Using this procedure, three PWAs performed significantly ($p < .05$) better on the CRTT-L-Cantonese than on the CRTT-R-$_{WF}$-Cantonese (PWA15, difference = 2.34; PWA17, difference = 2.75; PWA22, difference = 1.71) and one PWA performed significantly ($p < .05$) better on the CRTT-R-$_{WF}$-Cantonese than the CRTT-L-Cantonese (PWA4, difference = −6.43).

Lastly, ROC curves (Hajian-Tilaki, 2013) were generated on the overall and efficiency scores of the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese to obtain the optimal cutoff scores that differentiate the groups together with sensitivity and specificity scores (see Table 5 and Figure 1). The areas under the curve (AUC) were high (> 90%) for both the overall and efficiency scores for both CRTT-Cantonese tests. The CRTT-Cantonese's overall scores showed better diagnostic values than the efficiency scores. Furthermore, the overall scores from the CRTT-R-$_{WF}$-Cantonese showed higher diagnostic value than the CRTT-L-Cantonese. Table 5 presents different diagnostic values including AUC, sensitivity, specificity, and cutoff scores from the overall and efficiency scores for both CRTT-Cantonese tests.

Intermodality Association

A Pearson correlation coefficient was computed to evaluate the association between the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese in terms of the overall and efficiency scores for the PWAs and HCs to establish their comparability. The two CRTT-Cantonese tests yielded significant but relatively low correlations for the PWAs ($r = .42$, $p < .01$) and moderately high correlations for the HCs ($r = .73$, $p < .01$) for the score, along with similar correlations for the efficiency score (PWA: $r = .43$, $p < .01$; HC: $r = .62$, $p < .01$). Furthermore, the efficiency and overall scores were highly correlated with each other for both the CRTT-L-Cantonese (PWA: $r = .98$, $p < .01$; HC: $r = .80$, $p < .01$) and the CRTT-R-$_{WF}$-Cantonese (PWA: $r = .95$, $p < .01$; HC: $r = .90$, $p < .01$; see Hinkle et al., 2003). Furthermore, a regression analysis was computed to examine whether the performance in CRTT-L-Cantonese can be predicted by CRTT-R-$_{WF}$-Cantonese and vice versa. The result showed that the performance in CRTT-L-Cantonese can be predicted by performance in CRTT-R-$_{WF}$-Cantonese (and vice versa) in which 54% of the change in R^2 can be explained accordingly (beta = 0.74, $t = 9.25$, $SE = 0.07$, $p < .001$).

Concurrent Validity

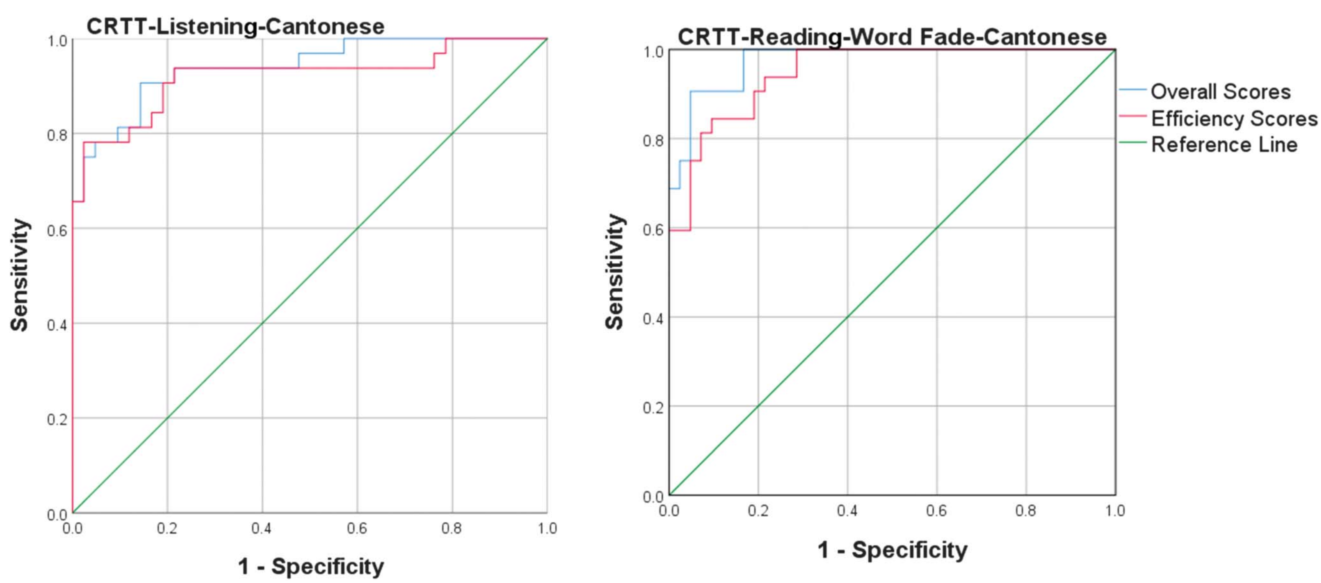
Concurrent validity was estimated by computing a Pearson correlation between the two CRTT-Cantonese tests' overall test scores and the AQ scores from CAB for PWAs and HCs separately. For PWAs, Pearson correlation coefficients yielded significant and moderately high correlations between the CRTT-L-Cantonese and CAB Auditory Comprehension scores ($r = .72$, $p < .01$), significant moderate correlations between CRTT-L-Cantonese and CAB AQ scores ($r = .62$, $p < .01$), and moderately

Table 5. Diagnostic accuracy of overall scores and efficiency scores in the Cantonese Computerized Revised Token Test Listening (CRTT-L-Cantonese) and Reading–Word Fade (CRTT-R-$_{WF}$-Cantonese) subtests.

CRTT test	Score	AUC [95% CI]	Cutoff	Sensitivity (%)	Specificity (%)
CRTT-L-Cantonese	Overall score	0.94 [0.89, 0.99]	13.75	100	42.90
	Efficiency score	0.92 [0.85, 0.99]	12.97	100	21.40
CRTT-R-$_{WF}$-Cantonese	Overall score	0.97 [0.95, 1.00]	13.12	100	83.30
	Efficiency score	0.95 [0.91, 0.99]	12.06	100	71.40

Note. Cutoff value is reported based on 100% sensitivity score. AUC = area under the curve; CI = confidence interval.

Figure 1. Receiver operating characteristic curves for overall and efficiency scores of the Cantonese Computerized Revised Token Test Listening (CRTT-Listening-Cantonese; left chart) and Reading (CRTT-Reading-Word Fade-Cantonese; right chart) subtests.



lower correlations between CRTT-R-$_{WF}$-Cantonese and CAB Reading scores (r = .49, p < .01), indicating acceptable concurrent validity of the tests for the PWA group (see Hinkle et al., 2003). There was a low positive but nonsignificant correlation between the CRTT-R-$_{WF}$-Cantonese and CAB AQ scores (r = .23, p = .23) for PWAs. For the HC group, no significant correlation was found between the CRTT-L-Cantonese and CAB Auditory Comprehension scores (r = .25, p = .11), probably due to the lack of variance in CAB Auditory Comprehension scores for this group. However, the other correlations were significant with low to moderate correlations for HC participants (see Table 6). It is notable that when the scores from both groups are combined together, significantly moderate to high correlations (see Hinkle et al., 2003) were found between the CRTT-Cantonese overall scores and different CAB scores (see Table 6).

Test–Retest Reliability

Test–retest reliability was calculated based on the data from 41 HCs (as one participant was not able to return for the retest) for both the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese. ICC yielded a correlation of .86 (p < .001) for the CRTT-L-Cantonese and .88 (p < .001) for the CRTT-R-$_{WF}$-Cantonese. Fifteen PWAs were randomly selected for retesting using the CRTT-L-Cantonese, and 16 PWAs were randomly selected for retesting using the CRTT-R-$_{WF}$-Cantonese. ICC yielded a high correlation of .96 (p < .001) for the CRTT-L-Cantonese and .82 (p < .01) for the CRTT-R-$_{WF}$-Cantonese in PWA. Furthermore, the standard error of measurement (*SEM*) based on the test–retest data was calculated based on the correlation coefficients using the formula ($SEM = SD\sqrt{1-r}$) where the average *SD* from the test and retest was used for both the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese for both participant groups. Overall, the *SEM* for the CRTT-L-Cantonese was lower (HC, 0.19; PWA, 0.29) than for the CRTT-R-$_{WF}$-Cantonese (HC, 0.21; PWA, 0.60).

Discussion

This study describes the procedures used for the translation and validation of the Cantonese listening and reading versions of the English CRTT. The construct validity, test sensitivity and specificity, cutoff scores, concurrent validity, and test–retest reliability data are provided for the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese. One aspect of construct validity, the ability of the test to differentiate HCs from PWAs, was evaluated with a repeated-measures ANOVA and ROC curve analyses. The repeated-measures ANOVA revealed that the HC group performed significantly better than the PWA group both on the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese and on both the overall accuracy and efficiency scores. This finding indicates that both tests differentiated the listening and reading comprehension of the PWA from the HCs at the group level. ROC curve analysis yielded an AUC greater than 0.90, which translates to excellent group separation power of CRTT-Cantonese tests. The results also showed that, at the highest sensitivity scores (100%), CRTT-L-Cantonese provided a lower specificity score of 42.90% while the CRTT-R-$_{WF}$-Cantonese provided a much higher specificity score of 83.30%. We caution that, although these scores from CRTT-Cantonese tests are effective for differentiating PWAs from HCs, they are insufficient for diagnosing the

Table 6. Pearson correlations between Cantonese Aphasia Battery (CAB) scores and Cantonese Computerized Revised Token Test Listening (CRTT-L-Cantonese) and Reading–Word Fade (CRTT-R-$_{WF}$-Cantonese) overall scores for healthy controls (HCs), persons with aphasia (PWA), and all participants.

Group	CAB scores	CRTT-L-Cantonese overall scores	CRTT-R-$_{WF}$-Cantonese overall scores
HC	CAB_AQ score	.45**	.54**
	CAB_AC score	.25	—
	CAB_Reading score	—	.36*
PWA	CAB_AQ score	.62**	.23
	CAB_AC score	.72**	—
	CAB_Reading score	—	.49**
All participants	CAB_AQ score	.81**	.68**
	CAB_AC score	.81**	—
	CAB_Reading score	—	.70**

Note. Em dashes indicate data not available. CAB_AQ = CAB Aphasia Quotient subtest; CAB_AC = CAB Auditory Comprehension subtest.

*$p \leq .05$. **$p \leq .01$.

presence of aphasia per se. Additional evidence for the presence of aphasia beyond performance on the CRTT is required to meet the definition and criteria for this specific pathological diagnosis (see McNeil & Pratt, 2001, for possible criteria). While no participants from either group performed at floor or ceiling level using either scoring metric, it will be important that future research establishes the sensitivity and specificity of tests for measuring levels of listening or reading comprehension for a larger group of PWAs and for other pathological populations such as dementia, developmental language and learning disorders, or psychiatric disorders such as depression or schizophrenia.

The current research adopted the self-paced word fade version of the English reading CRTT (CRTT-R-$_{WF}$) from the three reading versions developed and reported by McNeil et al. (2015). This version is judged to be most similar to the listening CRTT (CRTT-L) in terms of the sequential, word-by-word presentation of the stimuli, without the opportunity to review previous words and thus review content before responding (McNeil et al., 2015). This study revealed that both PWAs and HCs showed no significant difference in performance between the CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese tests. Furthermore, the results showed significant, positive, and moderate-to-high correlations between the Cantonese listening and reading versions of the test, both in terms of the overall and efficiency scores for both groups, establishing a high degree of detection of pathology for both CRTT-Cantonese tests. Furthermore, using RSDT as the criterion, three PWAs performed more poorly on the CRTT-R-$_{WF}$-Cantonese than on the CRTT-L-Cantonese, and one PWA performed more poorly on the CRTT-L-Cantonese than on the CRTT-R-$_{WF}$-Cantonese. This latter finding was also found in the English CRTT study (McNeil et al., 2015). This result found that about 87% of the PWAs performed comparably across both CRTT tests in Cantonese. Importantly, when large modality differences do occur between the two CRTT-Cantonese tests, an explanation other than the shared deficit affecting central language processing, that is, aphasia and measured by these tests, would be hypothesized. That is, while significantly higher performance in one modality was rare in this sample of PWAs, modality differences can occur, and these well-matched tests requiring comparable linguistic and other cognitive demands are capable of detecting these differences when present. Though still to be tested, it is predicted that modality differences will be detectable in nonaphasic syndromes such as pure alexia or word deafness, and these tests will aid in these differential diagnoses.

These results and predictions are also in line with the hypothesis that sentence comprehension in terms of the syntactic processing is modality general and depends on central language processing (DeDe, 2012, 2013). In fact, the nature of the language comprehension in the CRTT is highly dependent on the syntactic processing skills as well. Therefore, since the CRTT minimizes the lexical diversity, a comparable performance across the CRTT-R-$_{WF}$-Cantonese and the CRTT-L-Cantonese would be predicted. These results are especially interesting despite the fact that there were some, though minimal, differences in terms of the lexical items used between the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese and confirm that these differences were not sufficient to tax performance in one modality over the other. In general and in the absence of peripheral (diminished visual or auditory acuity) or more central perceptual (auditory or visual agnosia) impairments and also reading specific impairments (e.g., letter recognition or grapheme-to-phoneme conversion impairments), either test should provide an overall index of impairment of language comprehension in PWAs.

As summarized in Table 6, a measure of concurrent validity was evidenced by the moderate-to-high correlations between the CAB subtest scores and both the CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese tests when the data from both participant groups are combined. However, the correlations were mainly moderate for the PWA group and low for the HC group, reflecting the small distribution of scores especially for the HC group—findings that are consistent with those reported for the English versions (McNeil et al., 2015). Although there was no significant correlation between the CAB AQ score and the CRTT-R-$_{WF}$-Cantonese among PWAs, it is notable that the reading scores are not counted toward the calculation of the CAB overall AQ scores. Chen et al. (2013) reported an overall high concurrent validity in terms of correlation between the CRTT-Mandarin scores and the Concise Chinese Aphasia Test (r = .75) when all participants were combined (i.e., both PWAs and HCs). It was notable that similar results were found for this study when a correlation was computed between the CRTT-Cantonese scores and different CAB scores of all participants (see Table 6).

As discussed, high test–retest reliability was found between the initial testing and retesting for both the CRTT-L-Cantonese and CRTT-R-$_{WF}$-Cantonese tests and for both scoring metrics, especially for the PWA group. A similarly high test–retest reliability (ICC = .83, p < .01; see Hinkle et al., 2003) is also reported for the Turkish version of the CRTT-L among healthy adults (Turkyilmaz & Belgin, 2012). As with Cantonese, Yiu (1992) reported a high test–retest reliability (r = .99) for the CAB Auditory Comprehension subtest among a smaller group of seven Cantonese-speaking PWAs. However, he did not report any measure for the test–retest reliability for the CAB Reading subtest. Additionally, the *SEM* was comparable and relatively small for both groups. Again, these findings are consistent with those reported for the English versions (McNeil et al., 2015), confirming high test–retest reliability for the CRTT-Cantonese tests.

This study documents a reliable, valid, and sensitive tool for the assessment of listening and reading comprehension in aphasia for Cantonese language users. It also provides preliminary normative data on language comprehension for a Hong Kong sample of PWAs and HCs. These data motivate both within and outside Asia cross-cultural and cross-linguistic (e.g., Sino-Tibetan vs. Indo-European languages) comparisons of language processing ability in PWAs. However, while it is important to do so in future research, it is beyond the scope and purpose of this study to develop normative data and to examine the effects of aphasia severity, aetiology of the brain damage, socioeconomic status, and linguistics background on performance on the CRTT-Cantonese tests. Further psychometric properties that are not investigated here, such as within-subtest item homogeneity, will be considered for future research. While the sample size for this study is comparable with others examining translation and psychometric development of the CRTT and other tests and is sufficient to establish the validity and test–retest reliability of the tests, it is acknowledged that it is relatively small, and future studies would benefit from a larger sample and be required for norming the tests. Further research should also be directed to the development of the CRTT-Cantonese as a language assessment tool for other age groups including children and also other disordered populations without aphasia but with other cognitive and language processing impairments.

Conclusions

This research reports the development of the CRTT-Cantonese for the assessment of reading and listening comprehension in PWAs. Overall, these results suggest that a successful translation of the English listening and reading CRTT has been achieved as evidenced by translation verification procedures and test performance. Additionally, both listening and reading comprehension tests successfully differentiate PWAs from HCs, with the reading test providing somewhat better sensitivity and specificity. The lack of significant differences between the reading and listening comprehension performance on the group and individual participant bases, along with a significantly moderate-to-high correlation between them, is consistent with the findings from the English test versions and suggests that the overall severity of language processing impairment in PWAs, as measured by the CRTT, manifests similarly for most individuals across the auditory and visual modalities. Lastly, both the CRTT-L-Cantonese and the CRTT-R-$_{WF}$-Cantonese have acceptable concurrent validity relative to the CAB, and both achieved high test–retest reliability.

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Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Touch the black circle.			
CRTT-L	I1	指出黑色嘅圓圈。	1	6	7
CRTT-R	I1	指出黑色的圓圈。			
		Touch the red circle.			
CRTT-L	I2	指出紅色嘅圓圈。	1	6	7
CRTT-R	I2	指出紅色的圓圈。			
		Touch the blue square.			
CRTT-L	I3	指出藍色嘅正方形。	1	7	8
CRTT-R	I3	指出藍色的正方形。			
		Touch the green square.			
CRTT-L	I4	指出綠色嘅正方形。	1	7	8
CRTT-R	I4	指出綠色的正方形。			
		Touch the white circle.			
CRTT-L	I5	指出白色嘅圓圈。	1	6	7
CRTT-R	I5	指出白色的圓圈。			
		Touch the green circle.			
CRTT-L	I6	指出綠色嘅圓圈。	1	6	7
CRTT-R	I6	指出綠色的圓圈。			
		Touch the black square.			
CRTT-L	I7	指出黑色嘅正方形。	1	7	8
CRTT-R	I7	指出黑色的正方形。			

(*table continues*)

Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Touch the white square.			
CRTT-L	I8	指出白色嘅正方形。	1	7	8
CRTT-R	I8	指出白色的正方形。			
		Touch the blue circle.			
CRTT-L	I9	指出藍色嘅圓圈。	1	6	7
CRTT-R	I9	指出藍色的圓圈。			
		Touch the red square.			
CRTT-L	I10	指出紅色嘅正方形。	1	7	8
CRTT-R	I10	指出紅色的正方形。			
		Touch the big green circle.			
CRTT-L	II1	指出大嘅綠色圓圈。	1	7	8
CRTT-R	II1	指出大的綠色圓圈。			
		Touch the big black circle.			
CRTT-L	II2	指出大嘅黑色圓圈。	1	7	8
CRTT-R	II2	指出大的黑色圓圈。			
		Touch the little blue square.			
CRTT-L	II3	指出細嘅藍色正方形。	2	7	9
CRTT-R	II3	指出小的藍色正方形。			
		Touch the big red square.			
CRTT-L	II4	指出大嘅紅色正方形。	1	8	9
CRTT-R	II4	指出大的紅色正方形。			
		Touch the little red circle.			
CRTT-L	II5	指出細嘅紅色圓圈。	2	6	8
CRTT-R	II5	指出小的紅色圓圈。			
		Touch the little green square.			
CRTT-L	II6	指出細嘅綠色正方形。	2	7	9
CRTT-R	II6	指出小的綠色正方形。			
		Touch the little white square.			
CRTT-L	II7	指出細嘅白色正方形。	2	7	9
CRTT-R	II7	指出小的白色正方形。			
		Touch the big white circle.			
CRTT-L	II8	指出大嘅白色圓圈。	1	7	8
CRTT-R	II8	指出大的白色圓圈。			
		Touch the big blue circle.			
CRTT-L	II9	指出大嘅藍色圓圈。	1	7	8
CRTT-R	II9	指出大的藍色圓圈。			
		Touch the little black square.			
CRTT-L	II10	指出細嘅黑色正方形。	2	7	9
CRTT-R	II10	指出小的黑色正方形。			
		Touch the green square and the black square.			
CRTT-L	III1	指出綠色嘅正方形同埋黑色嘅正方形。	3	12	15
CRTT-R	III1	指出綠色的正方形和黑色的正方形。			
		Touch the blue circle and the green square.			
CRTT-L	III2	指出藍色嘅圓圈同埋綠色嘅正方形。	3	11	14
CRTT-R	III2	指出藍色的圓圈和綠色的正方形。			
		Touch the white circle and the blue square.			
CRTT-L	III3	指出白色嘅圓圈同埋藍色嘅正方形。	3	11	14
CRTT-R	III3	指出白色的圓圈和藍色的正方形。			
		Touch the black circle and the white square.			
CRTT-L	III4	指出黑色嘅圓圈同埋白色嘅正方形。	3	11	14
CRTT-R	III4	指出黑色的圓圈和白色的正方形。			
		Touch the green circle and the red square.			
CRTT-L	III5	指出綠色嘅圓圈同埋紅色嘅正方形。	3	11	14
CRTT-R	III5	指出綠色的圓圈和紅色的正方形。			
		Touch the red square and the white circle.			
CRTT-L	III6	指出紅色嘅正方形同埋白色嘅圓圈。	3	11	14
CRTT-R	III6	指出紅色的正方形和白色的圓圈。			
		Touch the white square and the green circle.			
CRTT-L	III7	指出白色嘅正方形同埋綠色嘅圓圈。	3	11	14
CRTT-R	III7	指出白色的正方形和綠色的圓圈。			

(*table continues*)

Appendix (p. 3 of 6)

Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Touch the black square and the red circle.			
CRTT-L	III8	指出黑色嘅正方形同埋紅色嘅圓圈。	3	11	14
CRTT-R	III8	指出黑色的正方形和紅色的圓圈。			
		Touch the red circle and the white circle.			
CRTT-L	III9	指出紅色嘅圓圈同埋白色嘅圓圈。	3	10	13
CRTT-R	III9	指出紅色的圓圈和白色的圓圈。			
		Touch the blue square and the black circle.			
CRTT-L	III10	指出藍色嘅正方形同埋黑色嘅圓圈。	3	12	15
CRTT-R	III10	指出藍色的正方形和黑色的圓圈。			
		Touch the big green square and the little black square.			
CRTT-L	IV1	指出大嘅綠色正方形同埋細嘅黑色正方形。	4	13	17
CRTT-R	IV1	指出大的綠色正方形和小的黑色正方形。			
		Touch the big black square and the little red circle.			
CRTT-L	IV2	指出大嘅黑色正方形同埋細嘅紅色圓圈。	4	12	16
CRTT-R	IV2	指出大的黑色正方形和小的紅色圓圈。			
		Touch the big blue circle and the little green square.			
CRTT-L	IV3	指出大嘅藍色圓圈同埋細嘅綠色正方形。	4	12	16
CRTT-R	IV3	指出大的藍色圓圈和小的綠色正方形。			
		Touch the big white circle and the little blue square.			
CRTT-L	IV4	指出大嘅白色圓圈同埋細嘅藍色正方形。	4	12	16
CRTT-R	IV4	指出大的白色圓圈和小的藍色正方形。			
		Touch the little blue square and the big black square.			
CRTT-L	IV5	指出細嘅藍色正方形同埋大嘅黑色正方形。	4	13	17
CRTT-R	IV5	指出小的藍色正方形和大的黑色正方形。			
		Touch the little green circle and the big red square.			
CRTT-L	IV6	指出細嘅綠色圓圈同埋大嘅紅色正方形。	4	12	16
CRTT-R	IV6	指出小的綠色圓圈和大的紅色正方形。			
		Touch the little black circle and the little white square.			
CRTT-L	IV7	指出細嘅黑色圓圈同埋細嘅白色正方形。	5	11	16
CRTT-R	IV7	指出小的黑色圓圈和小的白色正方形。			
		Touch the little white square and the big green circle.			
CRTT-L	IV8	指出細嘅白色正方形同埋大嘅綠色圓圈。	4	12	16
CRTT-R	IV8	指出小的白色正方形和大的綠色圓圈。			
		Touch the little red circle and the big blue circle.			
CRTT-L	IV9	指出細嘅紅色圓圈同埋大嘅藍色圓圈。	4	11	15
CRTT-R	IV9	指出小的紅色圓圈和大的藍色圓圈。			
		Touch the big red square and the big white circle.			
CRTT-L	IV10	指出大嘅紅色正方形同埋大嘅白色圓圈。	3	13	16
CRTT-R	IV10	指出大的紅色正方形和大的白色圓圈。			
		Put the black square by the red circle.			
CRTT-L	V1	將黑色正方形放喺紅色圓圈嘅側邊。	3	12	15
CRTT-R	V1	將黑色正方形放在紅色圓圈的旁邊。			
		Put the black circle above the white square.			
CRTT-L	V2	將黑色圓圈放喺白色正方形嘅上面。	2	13	15
CRTT-R	V2	將黑色圓圈放在白色正方形的上面。			
		Put the blue square before the black circle.			
CRTT-L	V3	將藍色正方形放喺黑色圓圈嘅前面。	2	13	15
CRTT-R	V3	將藍色正方形放在黑色圓圈的前面。			
		Put the red circle on the blue circle.			
CRTT-L	V4	將紅色圓圈放喺藍色圓圈嘅前面。	2	12	14
CRTT-R	V4	將紅色圓圈放在藍色圓圈的前面。			
		Put the blue circle behind the green square.			
CRTT-L	V5	將藍色圓圈放喺綠色正方形嘅後面。	2	13	15
CRTT-R	V5	將藍色圓圈放在綠色正方形的後面。			
		Put the green square under the black square.			
CRTT-L	V6	將綠色正方形放喺黑色正方形嘅下面。	2	14	16
CRTT-R	V6	將綠色正方形放在黑色正方形的下面。			

(*table continues*)

Appendix (p. 4 of 6)

Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Put the white circle below the blue square.			
CRTT-L	V7	將白色圓圈放喺藍色正方形嘅下面。	2	13	15
CRTT-R	V7	將白色圓圈放在藍色正方形的下面。			
		Put the white square next to the green circle.			
CRTT-L	V8	將白色正方形放喺綠色圓圈嘅側邊。	3	12	15
CRTT-R	V8	將白色正方形放在綠色圓圈的旁邊。			
		Put the red square in front of the white circle.			
CRTT-L	V9	將紅色正方形放喺白色圓圈嘅前面。	2	13	15
CRTT-R	V9	將紅色正方形放在白色圓圈的前面。			
		Put the green circle beside the red square.			
CRTT-L	V10	將綠色圓圈放喺紅色正方形嘅側邊。	3	12	15
CRTT-R	V10	將綠色圓圈放在紅色正方形的旁邊。			
		Put the big red square in front of the big white circle.			
CRTT-L	VI1	將大嘅紅色正方形放喺大嘅白色圓圈嘅前面。	4	15	19
CRTT-R	VI1	將大的紅色正方形放在大的白色圓圈的前面。			
		Put the big blue circle before the little green square.			
CRTT-L	VI2	將大嘅藍色圓圈放喺細嘅綠色正方形嘅前面。	5	14	19
CRTT-R	VI2	將大的藍色圓圈放在小的綠色正方形的前面。			
		Put the little green circle under the big red square.			
CRTT-L	VI3	將細嘅綠色圓圈放喺大嘅紅色正方形嘅下面。	5	14	19
CRTT-R	VI3	將小的綠色圓圈放在大的紅色正方形的下面。			
		Put the big black square above the little red circle.			
CRTT-L	VI4	將大嘅黑色正方形放喺細嘅紅色圓圈嘅上面。	5	14	19
CRTT-R	VI4	將大的黑色正方形放在小的紅色圓圈的上面。			
		Put the little black circle below the little white square.			
CRTT-L	VI5	將細嘅黑色圓圈放喺細嘅白色正方形嘅下面。	6	13	19
CRTT-R	VI5	將小的黑色圓圈放在小的白色正方形的下面。			
		Put the little blue square behind the big black circle.			
CRTT-L	VI6	將細嘅藍色正方形放喺大嘅黑色圓圈嘅後面。	5	14	19
CRTT-R	VI6	將小的藍色正方形放在大的黑色圓圈的後面。			
		Put the big green square by the little black square.			
CRTT-L	VI7	將大嘅綠色正方形放喺細嘅黑色正方形嘅側邊。	6	14	20
CRTT-R	VI7	將大的綠色正方形放在小的黑色正方形的旁邊。			
		Put the big white circle next to the little blue square.			
CRTT-L	VI8	將大嘅白色圓圈放喺細嘅藍色正方形嘅側邊。	6	13	19
CRTT-R	VI8	將大的白色圓圈放在小的藍色正方形的旁邊。			
		Put the little red circle beside the big blue circle.			
CRTT-L	VI9	將細嘅紅色圓圈放喺大嘅藍色圓圈嘅側邊。	6	12	18
CRTT-R	VI9	將小的紅色圓圈放在大的藍色圓圈的旁邊。			
		Put the little white square on the big green circle.			
CRTT-L	VI10	將細嘅白色正方形放喺大嘅綠色圓圈嘅前面。	5	14	19
CRTT-R	VI10	將小的白色正方形放在大的綠色圓圈的前面。			
		Put the black circle to the left of the white square.			
CRTT-L	VII1	將黑色圓圈放喺白色正方形嘅左邊。	2	13	15
CRTT-R	VII1	將黑色圓圈放在白色正方形的左邊。			
		Put the red square to the left of the white circle.			
CRTT-L	VII2	將紅色正方形放喺白色圓圈嘅左邊。	2	13	15
CRTT-R	VII2	將紅色正方形放在白色圓圈的左邊。			
		Put the black square to the right of the red circle.			
CRTT-L	VII3	將黑色正方形放喺紅色圓圈嘅右邊。	2	13	15
CRTT-R	VII3	將黑色正方形放在紅色圓圈的右邊。			
		Put the blue circle to the left of the green square.			
CRTT-L	VII4	將藍色圓圈放喺綠色正方形嘅左邊。	2	13	15
CRTT-R	VII4	將藍色圓圈放在綠色正方形的左邊。			
		Put the green circle to the left of the red square.			
CRTT-L	VII5	將綠色圓圈放喺紅色正方形嘅左邊。	2	13	15
CRTT-R	VII5	將綠色圓圈放在紅色正方形的左邊。			
		Put the white square to the right of the green circle.			
CRTT-L	VII6	將白色正方形放喺綠色圓圈嘅右邊。	2	13	15
CRTT-R	VII6	將白色正方形放在綠色圓圈的右邊。			

(*table continues*)

Appendix (p. 5 of 6)

Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Put the red circle to the right of the blue circle.			
CRTT-L	VII7	將紅色圓圈放喺藍色圓圈嘅右邊。	2	12	14
CRTT-R	VII7	將紅色圓圈放在藍色圓圈的右邊。			
		Put the white circle to the right of the blue square.			
CRTT-L	VII8	將白色圓圈放喺藍色正方形嘅右邊。	2	13	15
CRTT-R	VII8	將白色圓圈放在藍色正方形的右邊。			
		Put the blue square to the left of the black circle.			
CRTT-L	VII9	將藍色正方形放喺黑色圓圈嘅左邊。	2	13	15
CRTT-R	VII9	將藍色正方形放在黑色圓圈的左邊。			
		Put the green square to the right of the black square.			
CRTT-L	VII10	將綠色正方形放喺黑色正方形嘅右邊。	2	14	16
CRTT-R	VII10	將綠色正方形放在黑色正方形的右邊。			
		Put the little green circle to the left of the big red square.			
CRTT-L	VIII1	將細嘅綠色圓圈放喺大嘅紅色正方形嘅左邊。	5	14	19
CRTT-R	VIII1	將小的綠色圓圈放在大的紅色正方形的左邊。			
		Put the big white circle to the left of the little blue square.			
CRTT-L	VIII2	將大嘅白色圓圈放喺細嘅藍色正方形嘅左邊。	5	14	19
CRTT-R	VIII2	將大的白色圓圈放在小的藍色正方形的左邊。			
		Put the big green square to the right of the little black square.			
CRTT-L	VIII3	將大嘅綠色正方形放喺細嘅黑色正方形嘅右邊。	5	15	20
CRTT-R	VIII3	將大的綠色正方形放在小的黑色正方形的右邊。			
		Put the little white square to the right of the big green circle.			
CRTT-L	VIII4	將細嘅白色正方形放喺大嘅綠色圓圈嘅右邊。	5	14	19
CRTT-R	VIII4	將小的白色正方形放在大的綠色圓圈的右邊。			
		Put the big red square to the left of the big white circle.			
CRTT-L	VIII5	將大嘅紅色正方形放喺大嘅白色圓圈嘅左邊。	4	15	19
CRTT-R	VIII5	將大的紅色正方形放在大的白色圓圈的左邊。			
		Put the little black circle to the left of the little white square.			
CRTT-L	VIII6	將細嘅黑色圓圈放喺細嘅白色正方形嘅左邊。	6	13	19
CRTT-R	VIII6	將小的黑色圓圈放在小的白色正方形的左邊。			
		Put the little red circle to the right of the big blue square.			
CRTT-L	VIII7	將細嘅紅色圓圈放喺大嘅藍色正方形嘅右邊。	5	14	19
CRTT-R	VIII7	將小的紅色圓圈放在大的藍色正方形的右邊。			
		Put the big black square to the right of the little red circle.			
CRTT-L	VIII8	將大嘅黑色正方形放喺細嘅紅色圓圈嘅右邊。	5	14	19
CRTT-R	VIII8	將大的黑色正方形放在小的紅色圓圈的右邊。			
		Put the big blue circle to the left of the little green square.			
CRTT-L	VIII9	將大嘅藍色圓圈放喺細嘅綠色正方形嘅左邊。	5	14	19
CRTT-R	VIII9	將大的藍色圓圈放在小的綠色正方形的左邊。			
		Put the little blue square to the left of the big black circle.			
CRTT-L	VIII10	將細嘅藍色正方形放喺大嘅黑色圓圈嘅左邊。	5	14	19
CRTT-R	VIII10	將小的藍色正方形放在大的黑色圓圈的左邊。			
		Instead of the green square touch the black square.			
CRTT-L	IX1	唔好指出綠色正方形而係指出黑色正方形。	3	15	18
CRTT-R	IX1	不要指出綠色正方形而是指出黑色正方形。			
		Unless you have touched the white square, touch the green circle.			
CRTT-L	IX2	除非你已經指出白色正方形否則指出綠色圓圈。	0	17	17
CRTT-R	IX2	除非你已經指出白色正方形否則指出綠色圓圈。			
		If you have not touched the white circle, touch the blue square.			
CRTT-L	IX3	如果你未指出白色圓圈就指出藍色正方形。	0	17	17
CRTT-R	IX3	如果你未指出白色圓圈就指出藍色正方形。			
		Touch the green circle if you have not touched the red square.			
CRTT-L	IX4	如果你未指出紅色正方形就指出綠色圓圈。	0	17	17
CRTT-R	IX4	如果你未指出紅色正方形就指出綠色圓圈。			
		Either touch the red square or the white circle.			
CRTT-L	IX5	指出紅色正方形或者白色圓圈。	0	12	12
CRTT-R	IX5	指出紅色正方形或者白色圓圈。			

(*table continues*)

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Comparison Between the English Computerized Revised Token Test (CRTT) and Cantonese CRTT Listening (CRTT-L-Cantonese) and Reading (CRTT-RWF-Cantonese) Subtests

CRTT version	Subtest	Command	No. of different morphemes	No. of same morphemes	Total
		Touch the blue circle instead of the green square.			
CRTT-L	IX6	指出藍色圓圈而唔係綠色正方形。	2	12	14
CRTT-R	IX6	指出藍色圓圈而不是綠色正方形。			
		Touch either the red circle or the blue circle.			
CRTT-L	IX7	指出紅色圓圈或者藍色圓圈。	0	11	11
CRTT-R	IX7	指出紅色圓圈或者藍色圓圈。			
		Touch the black square if there is a red circle.			
CRTT-L	IX8	如果有一個紅色圓圈就指出黑色正方形。	0	16	16
CRTT-R	IX8	如果有一個紅色圓圈就指出黑色正方形。			
		Touch the blue square unless you have touched the black circle.			
CRTT-L	IX9	除非你已經指出黑色圓圈否則指出藍色正方形。	0	17	17
CRTT-R	IX9	除非你已經指出黑色圓圈否則指出藍色正方形。			
		If there is a black circle, touch the white square.			
CRTT-L	IX10	如果有一個黑色圓圈就指出白色正方形。	0	16	16
CRTT-R	IX10	如果有一個黑色圓圈就指出白色正方形。			
		Touch the big black square unless you have touched the little red circle.			
CRTT-L	X1	除非你已經指出細嘅紅色圓圈否則指出大嘅黑色正方形。	3	18	21
CRTT-R	X1	除非你已經指出小的紅色圓圈否則指出大的黑色正方形。			
		Touch the little blue square if there is a big black circle.			
CRTT-L	X2	如果有一個大嘅黑色圓圈就指出細嘅藍色正方形。	3	17	20
CRTT-R	X2	如果有一個大的黑色圓圈就指出小的藍色正方形。			
		Unless you have touched the little white square, touch the big green circle.			
CRTT-L	X3	除非你已經指出細嘅白色正方形否則指出大嘅綠色圓圈。	3	18	21
CRTT-R	X3	除非你已經指出小的白色正方形否則指出大的綠色圓圈。			
		If there is a big white circle, touch the little blue square.			
CRTT-L	X4	如果有一個大嘅白色圓圈就指出細嘅藍色正方形。	3	17	20
CRTT-R	X4	如果有一個大的白色圓圈就指出小的藍色正方形。			
		Touch the big blue circle instead of the little green square.			
CRTT-L	X5	指出大嘅藍色圓圈而唔係細嘅綠色正方形。	5	13	18
CRTT-R	X5	指出大的藍色圓圈而不是小的綠色正方形。			
		Touch the little green circle if you have not touched the big red square.			
CRTT-L	X6	如果你未指出大嘅紅色正方形就指出細嘅綠色圓圈。	3	18	21
CRTT-R	X6	如果你未指出大的紅色正方形就指出小的綠色圓圈。			
		Touch either the big green square or the little black square.			
CRTT-L	X7	指出大嘅綠色正方形或者細嘅黑色正方形。	3	14	17
CRTT-R	X7	指出大的綠色正方形或者小的黑色正方形。			
		Instead of the big red square, touch the big white circle.			
CRTT-L	X8	唔好指出大嘅紅色正方形而係指出大嘅白色圓圈。	5	16	21
CRTT-R	X8	不要指出大的紅色正方形而是指出大的白色圓圈。			
		If you have not touched the little black circle, touch the little white square.			
CRTT-L	X9	如果你未指出細嘅黑色圓圈就指出細嘅白色正方形。	4	17	21
CRTT-R	X9	如果你未指出小的黑色圓圈就指出小的白色正方形。			
		Either touch the little red circle or the big blue circle.			
CRTT-L	X10	指出細嘅紅色圓圈或者大嘅藍色圓圈。	3	12	15
CRTT-R	X10	指出小的紅色圓圈或者大的藍色圓圈。			
		Total	281	1212	1493