

# Taiwanese Traditional-Chinese Childhood Executive Functioning Inventory: Revision, Investigation of Psychometric Properties, and Establishing of Norms

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## Abstract

This study aimed to create a Taiwanese version of the Childhood Executive Functioning Inventory, examine the psychometric properties of the Taiwanese CHEXI (TC-CHEXI), and establish developmental norms of the TC-CHEXI. The original CHEXI is an open-access multilingual scale for measuring children's executive functioning (EF) comprising four subscales: working memory, planning, inhibition, and regulation. The responses of parents and teachers on the CHEXI can be used for primary screening of EF deficits. Our study consisted of three phases. (i) Phase One: After rewording the 26-item Hong Kong version of the CHEXI into Mandarin, a 24-item TC-CHEXI was established based on factor analyses of data from 130 children. (ii) Phase Two: more than 320 schools were randomly sampled and invited to join the study. A total of 2,821 parent ratings and 92 teacher ratings of children aged 4-12 years old were collected. The psychometric properties of this representative sample were examined and developmental norms were established. (iii) Phase Three: the TC-CHEXI and SNAP-IV of a separate sample ( $n = 133$ ) of fifth and sixth graders were collected to investigate how the two correlate. A 4-factor model with working memory, planning, inhibition and regulation constituting separate subscales demonstrated the best overall fit, except in the 4-year-old group. The TC-CHEXI and SNAP-IV were correlated. The TC-CHEXI is a valid tool that parents and teachers can use to evaluate the EF of Taiwanese children and may be used as a primary screening tool for educational and medical purposes.

**Keywords:** CHEXI, children, developmental norms, executive functioning, Taiwanese traditional-Chinese version

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## 「繁體中文兒童執行功能量表」(TC-CHEXI)： 編修、心理計量特質檢驗與常模建立

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### 摘要

本研究旨在編修適合臺灣本地使用的「繁體中文兒童執行功能量表」(Taiwanese Traditional Chinese Childhood Executive Functioning Inventory, TC-CHEXI)，並檢驗信效度與建立分齡本地 4 至 12 歲常模，做為初步篩檢執行功能缺損的參考。原量表有多種語言版本，包含四個次量表：工作記憶(WM)、計畫(PPLAN)、調適(REG)與抑制(INHIB)。TC-CHEXI 改編自香港繁體中文版本(原 26 題)，考慮臺灣中文使用習慣，逐字編修。本研究有三個階段：階段一初步研究使用編修後 26 題版本，以 130 名本地兒童為樣本，根據驗證性因素分析結果保留其中 24 題，並接著以探索性因素分析檢視四個次量表下的題項，進行微調。第二階段研究重新隨機抽樣，以複核驗證此一新四因子模式，並建立本地常模，全臺隨機抽出超過 320 所小學與幼兒園，全數發出邀請函，最後收回 2,821 位家長與 92 位教師填寫之有效問卷。家長的部分以驗證性因素分析重新檢視新的四因子模式，結果顯示四因子模式適配度最佳。本研究最後階段另以獨立抽樣的國小高年級學生樣本，檢驗共時效標效度。本研究結果支持 TC-CHEXI 各項心理計量指標皆顯示可做為工作記憶、計畫、調適與抑制等面向執行功能的初步篩選。本研究結果提供 4 至 12 歲分齡 TC-CHEXI 總分與次量表常模，除可供未來本地醫療臨床與教育實務／研究者使用之外，因 CHEXI 有多種語言版本，有利於跨國合作研究。

**關鍵詞：**兒童、兒童執行功能量表、執行功能、發展常模、繁體中文版

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## Introduction

Executive functioning (EF) refers to multidimensional self-directed advanced cognitive abilities that are critical for the behavioral and mental development of children (Barkley, 2014; Dawson & Guare, 2010; Goldstein, Naglieri, Princiotta, & Otero, 2014). The term EF is used as an umbrella concept to cover cognitive capabilities such as working memory, planning, inhibition, and regulation. EF develops over a long period of time, well into late adolescence and even adulthood. Researchers from various disciplines have been exploring EF-related issues, such as how EF predicts academic performance and social skills (Dawson & Guare, 2010; Goldstein et al., 2014; Simanowski & Krajewski, 2017) and how EF correlates with the psychiatric diagnoses of children (e.g. autism spectrum disorder (ASD) and attention deficiency and hyperactivity disorder (ADHD)) (Zimmerman, Ownsworth, O'Donovan, Roberts, & Gullo, 2017). In order to gain further knowledge of these relations, reliable and valid tools for assessing EF are necessary.

The EF of children can be measured through various means: (i) through EF tasks conducted with one child at a time under highly controlled settings (such as the go-no-go task and Flanker task) (Carlson, Zelazo, & Faja, 2013; Davidson, Amso, Anderson, & Diamond, 2006; Diamond, 2013; Lee, Bull, & Ho, 2013; Zhou, Chen, & Main, 2012); (ii) with inventories completed by parents and teachers (e.g. Childhood Executive Functioning Inventory, or CHEXI) (Thorell & Catale, 2014; Thorell & Nyberg, 2008). Both EF tasks and EF inventories have made unique contributions to the academic achievement (Thorell, 2007; Thorell, Veleiro, Siu, & Mohammadi, 2013). With regard to these two types of measures, EF tasks were considered as less efficient and less informative. On the other hand, EF inventories are less time consuming, with higher ecological validity, and with higher correlation to outcome variables of interests (Diamond, 2013; Naglieri & Goldstein, 2014). However, further research is required to gain better knowledge of how the parameters extracted from EF tasks can be further analyzed and what specific aspects that correlate with EF inventories and daily life functioning. Research on EF tasks and EF inventories are both essential for acquiring knowledge of EF, and the two research directions on EF can be

complementary.

Our primary goal of this study was to develop a valid EF inventory tool for use in Taiwan, which measures EF deficits specifically, but not psychiatric symptoms. The CHEXI is parent and teacher inventory for screening EF in children age 4 to 12 years (Thorell & Catale, 2014). Ratings are made on a 5-point Likert scale and a high score on the CHEXI indicates the necessity of further EF examination. Both the psychometric and cross-cultural aspects of the CHEXI are well established. The CHEXI is also an open-access and multilingual tool (<http://www.chexi.se>). The original 26-item version of the CHEXI was developed by Swedish scholars Thorell and Nyberg (Thorell & Catale, 2014; Thorell & Nyberg, 2008). It was then translated into different languages, including Chinese (Cantonese), English, Farsi, and French. The CHEXI was developed for measuring EF deficits specifically without including symptom levels as most previous EF measures. This would allow us to categorize children as having only EF deficits, only high ADHD symptom levels or both EF deficits and high ADHD symptom levels. This is not possible with previous EF scales as they include both EF deficits and symptoms within the same subscale. This should be important for education as for example working memory training would not be a suitable intervention for all children with ADHD, but only for those who have working memory deficits. Similarly, there could be children without ADHD who have poor working memory and they might be missed if using a screening instrument that combines both EF deficits and symptom levels. Developing a valid EF measuring tool would provide an excellent foundation for many future studies. Furthermore, with a psychometrically valid EF assessment tool, such as the original CHEXI, further investigations into EF-related issues can be conducted through a rigorous and scientific approach. Because the CHEXI is free to download and already used in many settings and in a variety of languages, developing a Taiwanese version of the CHEXI may contribute to more cross-cultural research in the future.

Theoretically, during development, EF structures may undergo phases of differentiation. When developing the CHEXI (Thorell & Catale, 2014; Thorell & Nyberg, 2008), items were selected based on the following four *a priori* subscales or EF factors: working memory (WM), planning (PLAN), inhibition (INHIB) and regulation (REG). However, when conducting a factor analysis, the original study of the CHEXI

identified only two main factors - working memory (combination of WM and PLAN subscales) and inhibition (combination of INHIB and REG subscales). Working memory involves the maintenance and manipulation of stored information while one is occupied by another task (Diamond, 2013). Participants are usually asked to remember some information while processing other information at the same time under artificial settings (Lee et al., 2013; Thorell, 2007; Zhou et al., 2012). If an inventory is used, questions that pertain to daily functions are asked, such as “Has difficulty remembering what he/she is doing, in the middle of an activity” (Thorell & Nyberg, 2008). Another core EF is inhibition. Proper inhibition enables the necessary management of reactions; thus, attention can be usefully allocated to perceptual stimuli or redirected to mental representation, resulting in the replacement of an inappropriate reaction with a preferable one (Davidson et al., 2006). EF factors that develop later in life, such as planning and regulation, are believed to be based on and derived from these two basic EF factors. We know from previous research that children’s EF skills develop over time (Akshoomoff, Brown, Bakeman, & Hagler, 2018; Davidson et al., 2006). However, little is known regarding how the factor structure of EF might change with age. In the present study, we therefore collected data from children age 4 to 12 years old in order to investigate whether the structure of EF evolves as children develop.

Aside from the CHEXI, other EF inventories have been established, such as the Behavior Inventory of Executive Function (Parent, Teacher, and Self-Report) (Naglieri & Goldstein, 2014; Roth, Erdodi, McCulloch, & Isquith, 2015), Barkley Deficits in Executive Function Scale-Children and Adolescents, Dalis Rating of Executive Functions, and Comprehensive Executive Functioning Inventory (Naglieri & Goldstein, 2014). Some published Chinese versions of these EF inventories have been used to test adults rather than typically developing children (Chang, 2011; Du, Qian, & Wang, 2010; Wu, Yu, Chen, & Guo, 2009). In 2014, when we began a series of EF inventory projects, no studies had included Taiwanese children as participants.

It was found in a previous study that the CHEXI correlated with ADHD symptoms in preschool children (Thorell, Eninger, Brocki, & Bohlin, 2010). Swanson, Nolan, and Pelham, Version IV (SNAP-IV) is a 26-item 4-point Likert scale with well-established reliability and validity that is used both clinically and in research. A Chin-

ese version of SNAP-IV has been created by a Taiwanese research team and used to screen ADHD symptoms (Liu, Huang, & Wang, 2013; Liu, Liu, Shang, Lin, Tu, & Gau, 2006). Because Taiwanese Traditional-Chinese Childhood Executive Function Inventory (or TC-CHEXI) is the first local EF inventories studies focusing on developing samples, and also because working memory and inhibition tests have been linked to ADHD (Messina Lde, Tiedemann, de Andrade, & Primi, 2006; Rodriguez-Jimenez, Cubillo, Jimenez-Arriero, Ponce, Aragues-Figuero, & Palomo, 2006), we would also like to investigate how the subscales of the TC-CHEXI correlate with the inattention and impulsivity/hyperactivity subscales of SNAP-IV.

At the time we started our phase one study, only the 26-item version of the CHEXI was available. We used the 26-item version of the Hong Kong Traditional Chinese CHEXI as a main reference to establish our local version. Later on, a new 24-item Hong Kong Traditional-Chinese CHEXI was included in a cross-cultural study (Thorell et al., 2013). The results showed that both the parent and teacher ratings of EF of children could be used to predict academic achievement in Sweden, Spain, and Iran. Further, the working memory subscale was a stronger predictor compared to the inhibition subscale. However, in Hong Kong, only teacher ratings were proved to be predictive. Establishing a local CHEXI version in Taiwan would be the first step for investigating this cross-cultural disparity.

### **Aims of the present study**

The primary aims of this study were to create a Taiwanese version of the Childhood Executive Functioning Inventory, examine the psychometric properties of the Taiwanese Traditional-Chinese CHEXI or TC-CHEXI, and establish developmental norms of the TC-CHEXI for local research and practical use.

The present study comprises three phases. The results for which are reported in the order of execution. Only the second phase is reported in detail. The first phase of the study involved revising the original 26-item Hong Kong CHEXI (which was a direct translation from the original 26-item CHEXI and the psychometric properties of it has not been published). A 24-item new Taiwan version of CHEXI (or TC-CHEXI) was established according to the empirical data of phase one. The second phase of the study involved investigating the psychometric properties of this newly revised TC-

CHEXI. The third phase of the study involved testing the concurrent criteria validity of the TC-CHEXI. The three studies were conducted with three different samples.

## Phase One

### Methods

#### Participants and Materials

In the first study, data were collected from the parents of 138 children aged 4 to 15 years old using the 26-item CHEXI (revised from the Hong Kong 26-item version to better suit local language usage). A total of 130 parents of children with a mean age of about 8 years ( $M = 8.64$  y,  $SD = 3.10$  y) provided complete data and were included in the analysis.

### Results

At the primary stage of data analyses, a confirmatory factor analysis (CFA) was applied to examine how the data fit the original 4-factor model of the 26-item CHEXI. The results of model fitting indexes supported the original model, with the exception of two items: (i) Item 25: “Thinks out loud, even when performing relatively simple tasks” (with CFA factor loading being only .19; this item also being deleted from the new 24-item CHEXI); and (ii) Item 10: “Gets overly excited when something special is going to happen (e.g., going on a field trip or to a party)” (with CFA factor loading being only .37). These two items were deleted from the TC-CHEXI. Therefore, only 24 of the 26 items were kept for later exploratory factor analysis (please see Appendix 1 for details of the 24 items).

After having deleted the two items, we conducted several exploratory factor analyses with the data from the 130 children. The 24 items in this stage of the study of the TC-CHEXI was not identical to the 24 items of the CHEXI of other languages. We conducted our research of revision empirically with the local sample, and revised the inventory accordingly. As it turned out, the item “Have difficulty understanding



the concept of time compared to same-aged peers” , which was originally included in the WM subscale of the 26-item CHEXI but was later deleted by the foreign research team due to low sampling adequacy, was proved to fit, however, with our local data ( $\chi^2 = 463.26$ ,  $df = 246$ ; the fit indexes of the CFA: RMSEA = .08; RMR = .06; GFI = .78; CFI = .85). This item appeared to show an even better fit when included in the PLAN subscale ( $\chi^2 = 436.79$ ,  $df = 246$ ; the fit indexes of the CFA: RMSEA = .08; RMR = .06; GFI = .80; CFI = .87), so we decided to keep the item in the newly revised 24-item TC-CHEXI, and move it from the WM subscale to the PLAN subscale.

To test the operation of this new 4-factor model, we had to cross-validate the model with another sample on the TC-CHEXI, which was to be completed in the second phase of this study. Because one of the 24 items in the TC-CHEXI was different from the CHEXI 24-item versions in other languages, the order assigned to each item and the calculation of the subscale scores were not identical to the other CHEXI versions. In conclusion, based on the empirical findings of the first phase of the study, the revised TC-CHEXI was proposed. The differences between the TC-CHEXI and the Hong Kong version were as follows: (i) the Chinese language usage in the TC-CHEXI was closer to the Mandarin used in Taiwan; (ii) we deleted one item from the Hong Kong version of the CHEXI (“Gets overly excited when something special is going to happen [e.g., going on a field trip or to a party]”); and (iii) we retained the item “Have difficulty understanding the concept of time compared to same-aged peers” and reassigned it to the PLAN subscale.

## Phase Two

### Method

#### Participants and Sampling Procedure

We used the stratified-cluster random-sampling procedure, with each school serving as a cluster, and invited a random sample of 320 elementary schools, preschools,



and kindergartens in Taiwan to participate in the study.

A proportional stratified-cluster random-sampling procedure was performed to select schools. A total of 2,385 preschools and kindergartens and 2,589 elementary schools were listed as cluster pools according to data retrieved from the government education website (<https://stats.moe.gov.tw/>). Each school was numbered and categorized to establish distinctions between preschools/kindergartens and elementary schools as well as one of the four geological locations of Taiwan (north, middle, south, and east). We then calculated the number of schools in each of the four geological locations, respectively. The following results were all shown in the order of north, middle, south, and east: (i) Preschools/kindergartens: 886, 551, 755, and 193; (ii) elementary schools: 771, 667, 951, and 200. We then calculated the percentage that each area comprised (preschools/kindergartens: 37.15%, 23.10%, 31.66%, and 8.09%; elementary schools: 29.78%, 25.76%, 36.73%, and 7.72%). The percentages formed the basis of our proportional stratified cluster.

After the schools had been randomly selected according to their percentage, invitation letters and emails as well as phone calls were used to contact them. Classroom teachers who were willing to help with our research assisted in the collection of both consent forms and TC-CHEXI forms from parents. Some parents who helped to complete the forms and agreed to participate in a follow-up and/or allow their child's teacher to help in the completion of the TC-CHEXI were contacted again approximately 1 month later for the collection of test-retest reliability data. A total of 2,821 parents replied with valid TC-CHEXI data (random missing data were replaced with the respective average). The age distribution of participants is presented in Table 1.

## Material

The revised 24-item TC-CHEXI established in the first phase of the study was used. A hardcopy version of the TC-CHEXI was provided for parents and teachers, and an identical web-based version was also provided for some of the teachers at their convenience. In addition to the 24 items, the age of child was requested at the end of the form.

## Results

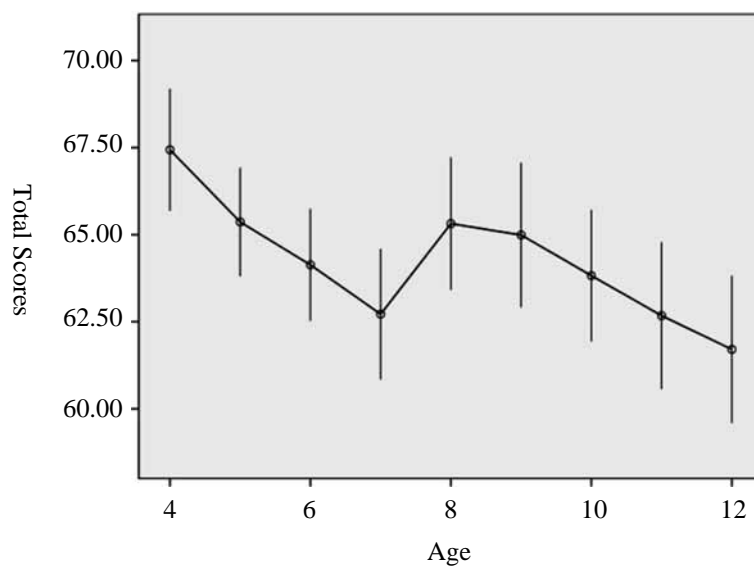
### Descriptive Statistical Results

The scores for the TC-CHEXI subscales for each age group are listed in Table 1 (with details of item numbers and scores noted under the table). Higher scores indicate higher EF deficits. All the skewness and kurtosis indexes of each age group were between -1 and +1, so could be considered normally distributed. With regard to effects of age on the total scores of the TC-CHEXI, a discontinuity of an otherwise linear decreasing pattern occurred at the age of 7 (Figure 1). If the curve is viewed in two separate parts, namely before 7-year-old and after 8-year-old, we can see two overall linear decreasing patterns; the first overall decreasing being from age 4 to 7 and the second being from age 8 to 12.

**Table 1.** *Summary on TC-TEXCI subscale scores by age including means (standard deviation; skewness; kurtosis)*

Age(N)	WM	PLAN	REG	INHIB	Total Scores
4 (361)	23.81 (6.69;0.52;0.71)	12.68 (4.15;0.50;0.25)	15.90 (3.95;-0.23;-0.16)	15.04 (4.00;-0.02;-0.24)	67.44 (16.94;.18;.40)
5 (327)	22.92 (5.45;0.08;0.40)	12.17 (3.34;0.32;0.52)	15.76 (3.72;-0.38;-0.02)	14.52 (3.87;0.17;0.18)	65.37 (14.31;-.14;.29)
6 (393)	22.30 (6.13;0.20;0.58)	11.73 (4.01;0.40;0.02)	15.65 (3.99;-0.23;0.09)	14.45 (4.22;-0.01;-0.31)	64.13 (16.21;.06;.45)
7 (295)	22.46 (6.46;0.22;-0.20)	11.41 (3.96;0.50;0.08)	15.32 (3.92;-0.25;0.00)	13.53 (3.99;0.04;-0.20)	62.72 (16.38;.15;-.01)
8 (297)	22.90 (6.38;-0.12;0.39)	11.91 (3.96;0.34;0.00)	16.07 (3.82;0.41;0.31)	14.43 (4.25;-0.09;-0.24)	65.32 (16.68;-.17;-.07)
9 (277)	22.86 (6.76;0.11;-0.03)	11.90 (4.27;0.49;0.11)	16.02 (4.21;-0.32;-0.29)	14.21 (4.15;0.20;-0.08)	65.00 (17.56;.05;-.05)
10 (343)	22.67 (6.86;0.19;-0.31)	11.72 (4.21;0.31;-0.27)	15.81 (4.09;-0.31;-0.35)	13.62 (4.33;0.08;-0.44)	63.83 (17.79;.03;-.38)
11 (280)	22.18 (6.99;0.21;-0.16)	11.48 (4.35;0.38;-0.32)	15.53 (4.08;-0.23;-0.19)	13.48 (4.26;0.00;-0.38)	62.68 (17.92;.04;-.14)
12 (248)	21.77 (6.42;0.21;-0.17)	11.10 (4.03;0.59;0.35)	15.64 (4.19;-0.28;-0.12)	13.20 (4.33;0.29;-0.13)	61.71 (16.92;.15;.09)

*Note:* WM (working memory, 9 items): 0-45; PLAN (plan, 6 items): 0-30; REG (regulation, 5 items): 0-25; INHIB (inhibition, 5 items): 0-25; Total Score (24 items): 0-120.



**Figure 1.** *Total Scores of TC-CHEXI across Age 4 to 12*

### Factor Structure Model

To examine the fitness of the last version of the TC-CHEXI, the following three models were tested through a confirmatory factor analysis. Model 1 contained 4 factors: WM, PLAN, REG and INHIB (see Table 2 for items under each factor and factor loading). Model 2 contained three factors: WM (WM and PLAN in model 1), REG and INHIB. Model 3 contained 2 factors: WM (WM and PLAN in Model 1), INHIB (REG and INHIB in Model 1). In addition to testing the models with the whole sample, model fitting was also conducted in each age group. We predicted that the EF structure should differentiate along the path of development.

**Table 2.** *Confirmatory Factor Analysis: Factor Loading (4 factored model)*

Items	WM	PLAN	REG	INHIB
1. Has difficulty remembering lengthy instructions	.65	--	--	--
2. Seldom seems to be able to motivate himself of herself to do something that he or she does not want to do	--	--	.54	--
3. Has difficulty remembering what he or she is doing in the middle of an activity	.62	--	--	--
4. Has difficulty following through on less appealing tasks unless he or she is promised some type of reward for doing so	--	--	.67	--
5. Has a tendency to do things without first thinking about what could happen	--	--	--	.66
6. When asked to do several things, he or she only remembers the first or last	.72	--	--	--
7. Has difficulty coming up with a different way of solving a problem when he or she gets stuck	.64	--	--	--
8. When something needs to be done, he or she is often distracted by something more appealing	--	--	.73	--
9. Easily forgets what he or she is asked to fetch	.64	--	--	--
10. Has clear difficulties doing things that he or she finds boring	--	--	.69	--
11. Has difficulty planning for an activity (e.g., remembering to bring everything necessary for a field trip or things needed for school)	--	.67	--	--
12. Has difficulty holding back his or her activity despite being told to do so	--	--	--	.77
13. Has difficulty carrying out activities that require several steps (e.g., for younger children, getting completely dressed without reminders; for older children, doing all homework independently)	--	.73	--	--
14. To be able to concentrate, he or she must find the task appealing	--	--	.71	--
15. Has difficulty refraining from smiling or laughing in situations where it is inappropriate	--	--	--	.65
16. Has difficulty telling a story about something that has happened so that others may easily understand	--	.72	--	--
17. Has difficulty stopping an activity immediately upon being told to do so. For example, he or she needs to jump a couple of extra times or play on the computer a little bit longer after being asked to stop	--	--	--	.70

(continued)

**Table 2.** *Confirmatory Factor Analysis: Factor Loading (4 factored model)*

Items	WM	PLAN	REG	INHIB
18. Has difficulty understanding verbal instructions unless he or she is also shown how to do something	.76	--	--	--
19. Has difficulty with tasks or activities that involve several steps	--	.81	--	--
20. Has difficulty thinking ahead or learning from experience	.69	--	--	--
21. Acts in a wilder way compared with other children in a group (e.g., at a birthday party or during a group activity)	--	--	--	.58
22. Has difficulty doing things that require mental effort, such as counting backward	.64	--	--	--
23. Has difficulty keeping things in mind while he or she is doing something else	.75	--	--	--
24. Has difficulties understanding the concept of time compared with same-aged peers	--	.71	--	-

Note: WM = working memory; PLAN = planning; REG = regulation; INHIB = inhibition.

The results for model comparisons and fitness assessments are listed in Table 3, and indicated that, though all the three models showed fairly good fit, the 4-factor demonstrated the best fit among the three models, followed by the 3-factor model. This was based on the data of the following significant differences in *Chi-square* values among the models: (i) delta *Chi-square* between the 2-factor model and 3-factor model = 253.33 ( $p \leq .001$ ;  $df = 2$ ); (ii) delta *Chi-square* between the 3-factor model and the 4-factor model = 100.26 ( $p \leq .001$ ;  $df = 3$ ). Further examination of the model fitness for each age group (Table 4) revealed that only the youngest age group (i.e., 4-year-olds) did not demonstrate the same fitness results.

**Table 3.** *Fitness indexes of 4-, 3- and 2-factor models*

Factors	<i>df</i>	<i>Chi-Square</i>	GFI	CFI	RMSEA	SRMR
4	246	2761.36	0.92	0.93	0.06	0.04
3	249	2861.62	0.91	0.92	0.06	0.04
2	251	3114.95	0.90	0.92	0.06	0.04

**Table 4.** *Fitness indexes of 4- and 3-factor models by age*

Age	Factors	df	Chi-Square	GFI	CFI	RMSEA	SRMR
4	4	246	704.77	0.86	0.91	0.07	0.05
	3	249	705.35	0.86	0.91	0.07	0.05
5	4	246	701.46	0.85	0.87	0.08	0.05
	3	249	725.29	0.85	0.87	0.08	0.05
6	4	246	763.98	0.86	0.90	0.07	0.05
	3	249	779.93	0.85	0.89	0.07	0.05
7	4	246	748.78	0.81	0.87	0.08	0.06
	3	249	766.25	0.80	0.86	0.08	0.06
8	4	246	620.75	0.84	0.90	0.07	0.05
	3	249	631.52	0.84	0.90	0.07	0.05
9	4	246	474.36	0.83	0.94	0.06	0.04
	3	249	492.40	0.87	0.93	0.06	0.04
10	4	246	565.35	0.88	0.93	0.06	0.04
	3	249	587.72	0.87	0.92	0.06	0.04
11	4	246	607.00	0.84	0.90	0.07	0.05
	3	249	623.70	0.83	0.90	0.07	0.05
12	4	246	529.09	0.86	0.90	0.07	0.05
	3	249	538.86	0.85	0.90	0.07	0.05

## Reliability

First, we examined the internal reliability of the four subscales and the overall scale with Cronbach alpha coefficients. The results were as follows: .88 (WM), .85 (PLAN), .80 (REG), and .80 (INHIB) for the four subscales; and .95 for the overall scale. The correlation coefficients between the four subscales are listed in Table 5. Overall, the results showed high correlations between the subscales, correlations ranging between .63 to .87.

We then investigated test-retest reliability based on data from 52 parents who consented to a follow-up and a second completion of the TC-CHEXI. The test-retest cycles were performed at least 1 months apart. The test-retest reliabilities between the two scores for the two tests were .90 for the overall scale and .82 (WM); .74 (PLAN); .81 (REG); and .83 (INHIB) for the subscales.

**Table 5.** *Correlation between subscales*

Subscales	WM	PLAN	REG	INHIB
WM		.87*	.71*	.74*
PLAN			.63*	.71*
REG				.71*

Note: WM = working memory; PLAN = planning; REG = regulation; INHIB = inhibition.

\*  $p \leq .01$

For interrater reliability, 92 teachers completed the TC-CHEXI. A summary of the means and standard deviations of the results from parents and teachers for the same children is presented in Table 6. The interrater coefficients were .43 (WM), .58 (PLAN), .28 (REG), and .32 (INHIB), all of which were statistically significant at the .01 level.

**Table 6.** *Means (standard deviations) of parents and teachers (92 pairs)*

	Parents	Teachers
WM	21.89 (7.89)	20.91 (7.29)
PLAN	11.31 (4.50)	10.80 (4.39)
REG	14.90 (4.87)	14.36 (4.89)
INHIB	13.09 (4.77)	12.27 (4.85)
Total Scores	61.19 (20.49)	58.33 (19.69)

Note: WM = working memory; PLAN = planning; REG = regulation; INHIB = inhibition.

## Normative data

We established norms for local (Taiwanese) usage of the TC-CHEXI according to the psychometric results of the TC-CHEXI (Table 1). The norms can be used to convert the TC-CHEXI total and subscale scores from parents of children aged 4 to 12 years old into *t*-scores. Also, we calculated percentile data and listed the results in Appendix 2.



To conclude this phase of the study, the psychometric properties of the newly revised 24-item TC-CHEXI were proved to be fairly good with our representative sample. The model fitting indexes demonstrated that the developmental differentiation of EF at least from age 4 to 5. To further investigate the validity of the TC-CHEXI, a concurrent criteria validity test would be performed with another sample of children in the third phase of the study.

## Phase Three

### Methods and Materials

In the third phase of the study, ratings on the TC-CHEXI and the SNAP-IV were collected in a separate sample ( $n = 133$ ) of fifth and sixth graders to investigate correlations between them.

### Results

The subscales of the TC-CHEXI were expected to be correlated with the inattention and impulsivity/hyperactivity of the SNAP-IV. Our findings support this hypothesis; the correlation coefficients (Pearson's  $r$ ) between the 4 subscales of the TC-CHEXI and the inattention of the SNAP-IV were .63 (REG), .75 (PLAN), .77 (WM) and .77 (INHIB) (all statistically significant at the .01 level); the correlation coefficients (Pearson's  $r$ ) between the 4 subscales of the TC-CHEXI and the impulsivity/hyperactivity of the SNAP-IV were .49 (REG), .51 (WM), .53 (PLAN), and .62 (INHIB) (all statistically significant at the .01 level). Partial correlation coefficients between the four subscales and the TC-CHEXI and the SNAP-IV (each with the other 3 subscales of the TC-CHEXI controlled for) were calculated to explore how each of the subscales of the TC-CHEXI independently correlated to the SNAP-IV. The results showed that WM (.22 to the inattention;  $p \leq .05$ ) and INHIB (.39 to the inattention, .32 to the impulsivity/hyperactivity;  $p \leq .001$ ) independently correlated to SNAP-IV. The results revealed a fairly good pattern of concurrent criteria validity of the TC-CHEXI.

## Overall Discussion and Conclusion

On the path of establishing the tool of EF inventory for Taiwanese children, the TC-CHEXI, three phases of empirical research were conducted in the current study. In the first phase, we revised the original 26-item CHEXI and proposed the new 24-item TC-CHEXI. To cross-validate, in the second and third phase of the study, psychometric properties of the TC-CHEXI were examined with another two samples. The overall findings supported that the TC-CHEXI is a reliable and valid tool to measure the EF of the children in Taiwan.

Out of theoretical interest, in phase two of the study, a 4-factor model (WM, PLAN, INHIB, and REG), a 3-factor model (WM+PLAN, INHIB, and REG) and a 2-factor model (WM+PLAN and INHIB+REG) were compared. Data obtained from the representative overall sample revealed fair fit with all three models. When comparing the fitness indexes within each age group, the 4-factor model fit the best with one exception. For the 4-year-old group, the 3-factor model demonstrated the best fit for the youngest group in our sample. The findings from the second phase of the study may reflect how EF evolves through individual development to form a greater number of subcomponents.

Besides theoretical reasons, for future research, the subcomponents of the TC-CHEXI provide researchers with a better measurement of more specific EF constructs to help with determining how each subscale correlates to a specific feature of an EF task. Therefore, the TC-CHEXI with the four subscales provides researchers with a measuring tool that may produce fruitful results.

The interrater reliability of the subscales between the parents and the teachers were ranged from moderate to low. This finding may partially echo the results of a recent study (Krieger, Amador-Campos, & Peró-Cebollero, 2019). In Krieger and her colleagues (2019), the Comprehensive Executive Function Inventory (CEFI) (Naglieri & Goldstein, 2014) was used to test adolescents with and without ADHD. It was found that the interrater correlations between parents and teachers was non-significant for most of the CEFI scales in the ADHD group. The scores of the CHEXI and other behavioral EF tools such as the CEFI might partially reflect individual rater's

subjective standard (Thorell & Catale, 2014). Thus, the interrater correlations were not too high. However, when the CHEXI was used to screen ADHD, the agreement between parents and teachers were well above 70% (Thorell et al., 2010). Therefore, the CHEXI and the TC-CHEXI might still be fairly consistent as a screening tool. This requires further study with local samples.

An examination of raw scores to assess the developmental trend revealed that the pattern was not as smooth as expected. The pattern exhibited a decreasing trend (indicating higher EF) from ages 4 to 7, and another increasing trend from age 8 to 12, but a discontinuity between age 7 and 8. Post hoc analyses revealed that the discrepancies in pattern change were all statistically significant. This discontinuity suggested that (i) adults might evaluate children's EF against subjective standards and the standards might reflect the standards from children's environment (because the age 7 is the age children in Taiwan starting elementary school education); and (ii) when conducting TC-CHEXI studies for various age groups, raw scores may not be as useful for formulating predictions. Rather, the use of percentile or *t*-scores that have been created based on normative data from a large number of children may be more methodologically sound. As emphasized in previous research (Thorell, Christiansen, Hammar, Berggren, Zander, & Bölte, 2018), norms for a rating inventories could vary substantially between different countries. It is therefore essential for us to examine the issue and establish country-specific norms for the Taiwanese version of the CHEXI.

To propose future studies, the TC-CHEXI may be a starting point for conducting research on the following topics. (i) The relatively weak correlation between teacher and parent ratings both in this study and in others suggests that further research should compare these responses with regard to predictability and related construct validity. (ii) Cross-sectional studies have dominated EF research, which means that more studies using a longitudinal design are needed. (iii) EF tasks, although they have been considered to be more specific in measuring subcomponents of EF, may still not be ecologically valid in terms of predicting daily functioning such as school performance (Hofmann, Schmeichel, & Baddeley, 2012; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). The TC-CHEXI can be included as a tool for empirically addressing these topics. Specifically, to answer the third research topic, evalu-

ations of antisaccade behavior through the use of eye-movement trackers or computers have been conducted to measure inhibitory control (Luna, Velanova, & Geier, 2008; Shelton et al., 2014). Therefore, future studies should test how the INHIB subscale of the TC-CHEXI is correlated with antisaccade eye-movement patterns.

The findings of the three studies demonstrated that the TC-CHEXI is a valid and reliable EF inventory that can be completed by the parents of children ages 4 to 12 years old to compare the EF of a specific child with norms. Although slightly different from the other 24-item CHEXI versions with regard to one item and the allocation of another item to a different scale, the 24-item TC-CHEXI can be used to conduct a cross-cultural study with scores for the four subscales. It is also a convenient and efficient tool for investigating the EF development in children in Taiwan, and for screening children in Taiwan with possible EF deficits.

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**Appendix 1. TC-CHEXI****「兒童執行功能量表」（臺灣繁體版本）（TC-CHEXI）（教師家長適用）**

以下是一系列的句子。請仔細閱讀每一個句子，由句子後的數字（從 1 到 5）裡，圈選出一個最能夠描述所評估孩子的數字。

完全不正確 1	不正確 2	部分正確 3	正確 4	完全正確 5					
1	很難記住冗長的指示。				1	2	3	4	5
2	似乎很少能激勵他去做一些自己不喜歡做的事。				1	2	3	4	5
3	活動進行到一半時，很難記得自己正在做什麼。				1	2	3	4	5
4	很難對一些欠缺吸引力的任務堅持到底，除非有人答應會給他獎勵。				1	2	3	4	5
5	傾向在做事之前不會先想到後果。				1	2	3	4	5
6	當有好幾件事情要他去做的時候，只會記得第一件或最後一件事情。				1	2	3	4	5
7	當他無法解決當下問題時，很難想出其他的方法。				1	2	3	4	5
8	當有些事情必須要完成的時候，他常常會因為其他更具吸引力的事情而分心。				1	2	3	4	5
9	很容易忘記別人要他／她拿什麼東西回來。				1	2	3	4	5
10	顯然難以去做一些他認為沉悶／無聊的事。				1	2	3	4	5
11	很難計畫好一項活動（例如：記得帶齊戶外教學的用品或上學所需要的東西）。				1	2	3	4	5
12	很難抑制他的行動，就算事前已經先告訴過他也一樣。				1	2	3	4	5
13	很難進行需要多個步驟的活動（例如：年紀較小的小孩在沒有提示下穿好衣服鞋襪；年紀較大的小孩獨自做完所有功課）。				1	2	3	4	5
14	他一定要覺得任務有吸引力才能全神貫注。				1	2	3	4	5
15	很難在不適宜笑的場合忍住不笑。				1	2	3	4	5
16	很難把已發生的事情說得讓別人可以聽懂。				1	2	3	4	5
17	即使被喝令停止，仍然很難在活動中立即停下來，例如：他在被喊停後總要多跳幾下，或是多玩電腦一會兒。				1	2	3	4	5
18	很難理解用言語表達的指示，除非同時向他示範怎樣做。				1	2	3	4	5
19	很難進行包含多個步驟的任務或活動。				1	2	3	4	5
20	很難預先想好未來的事或從經驗中學習。				1	2	3	4	5
21	在一群小朋友當中會表現得比其他人更瘋狂（例如：生日派對上或團體活動中）。				1	2	3	4	5
22	很難做一些需要動腦筋的事，例如：倒數（由二十倒數到一）。				1	2	3	4	5
23	當他在做一件事情時，很難將其他事情記在心裡面。				1	2	3	4	5
24	跟年紀差不多的人比起來，很難理解時間的概念。				1	2	3	4	5

**Appendix 2. Percentile of Subscale and Total Scores by Age**

Age (N)	Percentile	WM	PLAN	REG	INHIB	Total
4 (361)	25	19.0000	10.0000	13.0000	12.0000	57.0000
	50	23.0000	12.0000	16.0000	15.0000	68.0000
	75	28.0000	15.0000	18.6020	18.0000	77.0000
	90	32.0000	18.0000	21.0000	20.0000	87.0000
	95	36.0000	20.0000	22.0000	21.9000	99.0000
	97	39.1400	22.0000	23.0000	22.1400	103.0000
5 (327)	25	20.0000	10.0000	13.0000	12.0000	56.0000
	50	23.0000	12.0000	16.0000	15.0000	67.0000
	75	27.0000	15.0000	19.0000	17.0000	75.0000
	90	29.2603	16.0000	20.0000	19.0000	83.0000
	95	32.0000	18.0000	21.0000	21.0000	86.0000
	97	33.0000	18.0000	22.0000	23.0000	93.1600
6 (393)	25	19.0000	9.0000	13.0000	12.0000	55.0000
	50	22.0000	11.0000	15.0000	15.0000	64.0000
	75	26.0000	14.0000	19.0000	17.0000	74.0000
	90	30.0000	17.0000	20.0000	20.0000	84.0599
	95	32.0000	19.0000	21.3000	22.0000	91.5199
	97	34.0000	21.0000	23.0000	22.1800	96.0000
7 (295)	25	17.0000	9.0000	13.0000	11.0000	51.0000
	50	22.0000	11.0000	15.0000	14.0000	63.0000
	75	27.0000	14.0000	18.0000	16.0000	74.0000
	90	31.0000	17.0000	20.0000	19.0000	83.0000
	95	33.0000	18.0000	22.0000	20.0000	90.6000
	97	35.1200	20.0000	22.1200	21.0000	96.1200
8 (297)	25	19.0000	9.0000	14.0000	12.0000	54.5000
	50	23.0000	12.0000	16.0000	15.0000	66.0000
	75	28.0000	15.0000	18.0000	17.0000	77.0000
	90	31.0000	17.0000	21.0000	20.0000	85.0000
	95	33.0000	19.0000	22.1000	21.0000	92.0000
	97	35.0000	20.0000	23.0000	22.0600	96.1200
9 (277)	25	18.0000	9.0000	13.0000	11.0000	53.0000
	50	23.0000	12.0000	16.0000	14.0000	65.0000
	75	27.0000	14.1801	19.0000	17.0000	76.4884
	90	31.0000	17.0000	21.0000	20.0000	85.3270
	95	35.0000	20.0000	22.0000	21.1000	94.0000
	97	36.0000	21.6600	23.0000	23.0000	102.0000

(continued)

**Appendix 2. Percentile of Subscale and Total Scores by Age**

Age (N)	Percentile	WM	PLAN	REG	INHIB	Total
10 (343)	25	18.0000	8.0000	13.0000	11.0000	52.0000
	50	23.0000	12.0000	16.0000	14.0000	65.0000
	75	27.0000	14.2900	19.0000	17.0000	76.0000
	90	31.0000	17.0000	21.0000	19.0000	87.0000
	95	34.9276	19.8000	22.0000	21.0000	95.0000
	97	37.0000	21.0000	23.0000	22.0000	98.0000
11 (280)	25	17.0000	8.0000	13.0000	11.0000	49.0000
	50	23.0000	11.0000	16.0000	14.0000	64.0000
	75	27.0000	15.0000	19.0000	16.0000	74.7500
	90	31.0000	17.0000	20.0000	19.0000	85.0000
	95	34.0000	19.0000	22.0000	21.0000	90.0000
	97	34.0000	20.0000	23.0000	21.0000	95.0000
12 (248)	25	18.0000	8.0000	13.0000	10.0000	51.1952
	50	21.0000	11.0000	16.0000	13.0000	61.7407
	75	26.0000	14.0000	18.0000	16.0000	72.0000
	90	30.0000	16.0000	21.0000	19.0000	83.1159
	95	32.5500	18.5500	22.0000	21.0000	89.0000
	97	35.0000	19.5300	23.5300	23.0000	95.0600

Note: WM = working memory; PLAN = planning; REG = regulation; INHIB = inhibition.

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