科技部補助專題研究計畫成果報告
期末報告

漢語分類詞與量詞的分與合：探究其內在之認知機制與神經關連性(第3年)

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報 告 附 件 ： 移地研究心得報告
出席國際學術會議心得報告

中　華　民　國　107　年　03　月　31　日

中文摘要：漢語是典型的分類詞語言，在數詞(Num)與名詞(N)之間需用分類詞(C)，例如「五本書」，或量詞(M)，例如「五箱書」。許多語言學家，尤其是形式句法學家，認為C/M 應統合為同一範疇；然而也有許多學者堅稱兩者應分屬不同的類別。這個存在超過了半世紀的爭議在Her (2012a)的數學解釋中找到了一個突破：C/M 的分與合乃歸因於其數學功能上的分與合。(1) C/M 在數學上的分與合 (Her 2012a)[Num X N] = [[Num × X] N], where X = C iff X =1, otherwise X = M.將 [Num C/M]的關係解釋為乘法的關係可將C/M 統合為「被乘數」；其區分在於其質(value)的不同：C=1, M≠1。Her (2012b) 進一步在一個形式語言學的架構下分析，C/M 之「合」在於句法：二者為同一句法類別，二者之「分」在於語意：C 為修飾語並非述詞，因此語意有穿透性，M 為述詞，因此語意無穿透性。以上的看法解釋了為何在[Num C/M N]中C的訊息包含於N，因此C 是可省略的，但是在[Num C/M N] 中M 的訊息並不包含於N，因此M 是不可省略的。但是對於數量詞與分類詞是否與數詞的處理有相同的神經基礎，從既有的實驗研究中並無法得到定論。在一個最新的fMRI 實驗中，Cui et al (2013)發現分類詞的處理與工具名詞相似，與點陣和數目不同。然而，這項研究中所謂的classifiers 其實包含了大量的量詞，不僅未區分C 與M，也未區分出數值的M和非數值的M。此外，他們也沒有排除掉分類詞的語義屬性影響，這樣的混淆極可能導致實驗結果的失真。我們從數學的角度對於 C/M 的解讀所得到的預測是：具有數值的C 與M1-2 應與數詞的處理類似，而非一般名詞，例如工具名詞。因此本研究的目的有二：一、複製Cui et al (2013)的實驗派典，首先進行行為實驗，但在語料上區分數值的C&M1-2 與非數值的M3-4，並將材料以最小對立體呈現，以控制語義屬性。二、測試上述Her (2012a, 2012b)有關C/M 的數學理論。針對目的二，我們原先設計計畫採用促發作業來探究C/M 分與合的認知機制與其神經關連性，以點與文字二種表示數量的方式，首先檢視C/M 是否的確含有數量的概念，再進一步檢視C 與M 的被乘數角色。然而，多次促發作業實驗都無顯著效果，因此我們改變實驗派典，改採numerical Stroop作業，受試者須判斷語意數量或字型大小，透過檢驗C/M是否表現出典型數量處理時會出現的距離效果和一致效果來驗證Her (2012a, 2012b)的理論。實驗結果顯著，支持Her (2012a, 2012b)的理論：1.C/M 的確含有數量的概念、2.C與M扮演被乘數的角色。

中文關鍵詞：分類詞、量詞、乘法、認知機制、fMRI

英文摘要：The element in between a numeral (Num) and a noun (N) in Chinese, a textbook example of classifier languages, is recognized to be either a numeral classifier (C) or measure word (M). Many linguists, largely formalists, consider C/M converge as a single category, while others, many of them functionalists, claim that C and M diverge and form distinct categories. The stalemate lasted for more than half a century until a breakthrough in Her (2012a), which takes serious the mathematical interpretation of C/M and comes up with the most precise formulation for the C/M

distinction.(1) C/M Distinction in Mathematical Terms (Her 2012a:1679)$[\text{Num } X\ N] = [[\text{Num} \times X]\ N]$, where $X = C$ iff $X = 1$, otherwise $X = M$.This multiplication interpretation of [Num C/M] has C/M converge as the multiplicand and diverge in their respective value: $C=1$, $M \neq 1$. Her (2012b) further demonstrates within a formal linguistic framework that the C/M convergence is syntactically encoded as the two belong to the same syntactic category, but their divergence is semantic in nature: C is transparent in being a modifier and not a predicate, but M is opaque and thus a predicate. This view satisfactorily explains why C is redundant and can thus be omitted in the NP but M is not.However, existing empirical studies produce conflicting results. Cui et al (2013) found that the processing of classifiers is similar to that of tool nouns, but not that of numbers and dot arrays. However, the so-called classifiers in the study included lots of Ms. The C/M distinction was not made, nor was the distinction between numerical Ms and non-numerical Ms. Furthermore, they did not control the potential confound of semantic attributes of C/Ms. Such confusions can certainly distort the results of the experiments.The mathematical interpretation of C/M suggests that the numerical C and M1-2 should be similar to numbers in processing than to common nouns. The goal of this project is: 1) to determine whether C/M share the same neural basis with numbers in processing, by replicating the fMRI study in Cui et al (2013) but with better experimental control and selection of stimuli; 2) to further test the mathematical interpretation of C/M in Her (2012a, 2012b). Originally, we planned to use a priming task to investigate the cognitive mechanism underlying C/Ms. However, we could not observe significant priming effect after trying several priming experiments. Consequently, we changed priming task into numerical stroop task, in which participants had to choose the C/M phrase that denotes a larger quantity or has a larger font size. By examining whether C/Ms reflect distance effect and congruity effect as classic number processing, we would like to verify Her's (2012a, 2012b) theory. The distance effect is a phenomenon that comparing proximate digits is more difficult than comparing remote ones. The congruity effect emerges when congruent pairs lead to facilitation effect whereas incongruent pairs result in interference effect. Our results showed significant distance and congruity effect, supporting Her's (2012a, 2012b) theory.

英文關鍵詞： classifier, measure word, multiplication, cognitive mechanism, fMRI

科技部補助專題研究計畫成果報告

（□期中進度報告/■期末報告）

（計畫名稱）

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本計畫除繳交成果報告外，另含下列出國報告，共 _5_ 份：
■執行國際合作與移地研究心得報告
■出席國際學術會議心得報告
□出國參訪及考察心得報告

中　華　民　國　107　年　3　月　23　日

研究計畫中文摘要

漢語是典型的分類詞語言，在數詞(Num)與名詞(N)之間需用分類詞(C, classifier)，例如「五本書」，或量詞(M, measure word)，例如「五箱書」。許多語言學家，尤其是形式句法學家，認為C/M 應統合為同一範疇；然而也有許多學者堅稱兩者應分屬不同的類別。這個存在超過了半世紀的爭議在Her (2012a)的數學解釋中找到了一個突破：C/M 的分與合乃歸因於其數學功能上的分與合。

(1) C/M 在數學上的分與合 (Her 2012a:1679)

[Num X N] = [[Num × X] N], where X = C *iff* X =1, otherwise X = M.

將 [Num C/M]的關係解釋為乘法的關係可將C/M 統合為「被乘數」；其區分在於其質(value) 的不同：C=1, M≠1。Her (2012b) 進一步在一個形式語言學的架構下分析，C/M 之「合」在於句法：二者為同一句法類別 (syntactic category)，二者之「分」在於語意：C 為修飾語 (modifier) 並非述詞 (predicate)，因此語意有穿透性 (transparent)，M 為述詞(predicate)因此語意無穿透性(opaque)。

以上的看法解釋了為何在[Num C/M N]中C 的訊息包含於N，因此C 是可省略的，例如「五(張)餅二(條)魚」，但是在[Num C/M N] 中M 的訊息並不包含於N，因此M 是不可省略的，例如「五*(籃)餅二*(箱)魚」。

但是對於數量詞(quantifiers)與分類詞(classifiers)是否與數詞(numbers)的處理(processing)有相同的神經基礎，從既有的實驗研究中並無法得到定論。而在一個最新的fMRI 實驗中，Cui et al (2013)發現分類詞的處理與工具名詞(tool nouns)相似，與點陣(dot arrays)和數目不同。然而，這項研究中所謂的classifiers 其實包含了大量的量詞(measure words)，不僅未區分C與M，也未區分出數值的M和非數值的M。此外，他們也沒有排除掉在實驗中受試者的判斷可能受到分類詞的語義屬性影響，這樣的混淆極可能導致實驗結果的失真。

我們從數學的角度對於 C/M 的解讀所得到的預測是:具有數值的C 與M1-2 應與數詞的處理類似，而非一般名詞，例如工具名詞。因此本研究的目的有二：一、複製Cui et al (2013)的實驗派典，首先進行行為實驗，但是在語料上嚴格區分數值的C&M1-2 與非數值的M3-4，並且將材料以最小對立體呈現，以控制語義屬性可能造成的影響；待行為實驗結果明確後，再執行fMRI實驗。二、測試上述Her (2012a, 2012b)有關C/M 的數學理論。

針對目的二，我們原先設計計畫採用促發作業來探究C/M 分與合的認知機制與其神經關連性，以點與文字二種表示數量的方式，首先檢視C/M 是否的確含有數量的概念，再進一步檢視C 與M 在被乘數的特性上，是否C 是可省略的，而M 是不可省略的。然而，在計畫執行過程中，我們發現促發作業的效果雖有趨勢但是不達到統計上的顯著效果，且在修改實驗設計多次後，每次的結果均無法得到顯著的促發效果。因此我們改變實驗派典，將促發作業改為numerical Stroop作業，受試者須判斷語意數量或字型大小，透過檢驗C/M是否表現出典型數量處理時會出現的距離效果和一致效果來驗證Her (2012a, 2012b)的理論。距離效果是指，比較距離近的數字比起比較距離遠的數字困難，會有較低的正確率與較長的反應時間；一致性效果則是指當語義數量和字型大小一致時，有促進效果；當兩者不一致時，有干擾效果。實驗結果顯著，支持Her (2012a, 2012b)的理論：1.C/M 的確含有數量的概念、2.C與M扮演被乘數的角色。

關鍵詞：分類詞、量詞、乘法、認知機制、fMRI

Abstract

The element in between a numeral (Num) and a noun (N) in Chinese, a textbook example of classifier languages, is recognized to be either a numeral classifier (C) or measure word (M). Many linguists, largely formalists, consider C/M converge as a single category, while others, many of them functionalists, claim that C and M diverge and form distinct categories. The stalemate lasted for more than half a century until a breakthrough in Her (2012a), which takes serious the mathematical interpretation of C/M and comes up with the most precise formulation for the C/M distinction.

(1) C/M Distinction in Mathematical Terms (Her 2012a:1679)

[Num X N] = [[Num × X] N], where X = C *iff* X =1, otherwise X = M.

This multiplication interpretation of [Num C/M] has **C/M *converge* as the multiplicand and *diverge* in their respective value: C=1, M≠1**. Her (2012b) further demonstrates within a formal linguistic framework that the C/M convergence is syntactically encoded as the two belong to the same syntactic category, but their divergence is semantic in nature: C is transparent in being a modifier and not a predicate, but M is opaque and thus a predicate. This view satisfactorily explains why C is redundant and can thus be omitted in the NP but M is not.

However, existing empirical studies produce conflicting results. Cui et al (2013) found that the processing of classifiers is similar to that of tool nouns, but not that of numbers and dot arrays. However, the so-called classifiers in the study included lots of Ms. The C/M distinction was not made, nor was the distinction between numerical Ms and non-numerical Ms. Furthermore, they did not control the potential confound of semantic attributes of C/Ms. Such confusions can certainly distort the results of the experiments.

The mathematical interpretation of C/M suggests that the numerical C and $M_{1\text{-}2}$ should be similar to numbers in processing than to common nouns. The goal of this project is: 1) to determine whether C/M share the same neural basis with numbers in processing, by replicating the fMRI study in Cui et al (2013) but with better experimental control and selection of stimuli; 2) to further test the mathematical interpretation of C/M in Her (2012a, 2012b).

Originally, we planned to use a priming task to investigate the cognitive mechanism underlying C/Ms. However, we could not observe significant priming effect after trying several priming experiments. Consequently, we changed priming task into numerical stroop task, in which participants had to choose the C/M phrase that denotes a larger quantity or has a larger font size. By examining whether C/Ms reflect distance effect and congruity effect as classic number processing, we would like to verify Her's (2012a, 2012b) theory. The distance effect is a phenomenon that comparing proximate digits is more difficult than comparing remote ones. The congruity effect emerges when congruent pairs lead to facilitation effect whereas incongruent pairs result in interference effect. Our results showed significant distance and congruity effect, supporting Her's (2012a, 2012b) theory.

Key words: classifier, measure word, multiplication, cognitive mechanism, fMRI

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Mathematical Values in the Processing of Chinese Numeral Classifiers and Measure Words

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Introduction

Chinese is a numeral classifier language, where an element known as numeral classifier that denotes a unit is essential when a noun (N) is quantified by a numeral (Num). Numeral classifiers come in two varieties, sortal classifer (C) and measural classifier (M), also known as 'classifier' and 'measure word', respectively. In Table 1, *ben* and *ke* are classifiers (C); *xiang* (box) and *da* (dozen) are measure words (M). In this paper, the category of numeral classifiers is referred to as C/M.

(Insert Table 1 roughly here)

Table 1. Examples of Chinese numeral classifiers and measure words

Numeral Classifier (C)	**Measure Word (M)**
五　本　雜誌	五　箱　雜誌
wu　ben　zazhi	*wu　xiang　zazhi*
5　C　magazine	5　M-box magazine
'5 magazines'	'5 boxes of magazines'
十　顆　蘋果	十　打　蘋果
shi　ke　pingguo	*shi　da　pingguo*
10　C　apple	10　M-dozen　apple
'10 apples'	'10 dozens of apples'

C and M converge in that they appear in the same grammatical position and are mutually exclusive [1-3]. However, C and M diverge in that Cs qualify the noun but Ms quantify the noun [4-6]. To be more specific, Cs categorise nouns by highlighting certain salient or inherent properties of the noun, while Ms denote the quantity of the entity of the noun [5, 7]. For example, *ben* in Table 1 highlights the volume feature and can only be used for a bound copy of printed materials, such as a book or a magazine, whereas *xiang* means "a box of", which carries new information indicating the quantity of the noun being quantified, since a box can contain different amounts of any object.

This convergence and divergence between C and M were reconciled by Her [8], where an innovative mathematical view was proposed to interpret the relation between Num and C/M as multiplication. The distinction between C and M is encoded precisely as follows: [Num X N] = [[Num × X] N], where X = C iff X = 1, otherwise X = M. In other words, X being the element required between Num and N, X is C if its inherent mathematical value is 1; otherwise, X is M. For example, in *shi ke pingguo* (ten C apple), *shi* (ten) and *ke* (C) form a multiplicative unit, i.e., (10×1); likewise, in *shi da pingguo* (ten M-dozen apple), *shi* (ten) and *da* (M-dozen) also form a multiplicative unit, i.e., (10×12). Under this view, C and M thus converge as the multiplicand of Num, the multiplier. C and M occupy exactly the same syntactic position and thus belong to a single syntactic category. Yet, C and M diverge in terms of their respective inherent values: C = 1, M ≠ 1, and thus constitute two distinct subcategories.

Note that a multiplicand 1 is unique in that it is the only identity element, or neutral element, in multiplication; 1 is thus redundant in the multiplicative equation. A multiplicand with any other value, numerical or non-numerical, is not redundant. This unique property of multiplicand 1 can explain why Cs may behave differently from Ms, in spite of C/M as a single syntactic category [8].

Her and Wu [9] further proposed a taxonomy of the magnitude values that C/Ms encode, along two dimensions: numerical vs. non-numerical and fixed vs. variable (See Table 2). While M_1 and M_2 both encode numerical values, the former has fixed values and the latter does not. Likewise, M_3 and M_4 both encode non-numerical values, but the former has fixed values and the latter does not. Thus, C, M_1 and M_3 encode fixed values, while M_2 and M_4 do not.

(Insert Table 2 roughly here)

Table 2. Types of mathematical values denoted by C/Ms

Numerical	**Fixed**	n = 1 **e.g., *ben* (本), *ke* (顆), *tiao* (條), *zhi* (隻)**	**C**
		n = 2 e.g., *duei* (pair 對); **n = 12** e.g., *da* (dozen 打)	M_1
	Variable	**n > 1** e.g., *pai* (row 排), *bang* (gang 幫), *die* (stack 疊)	M_2
Non-numerical	Fixed	e.g., *gongjin* (kilogram 公斤), *gongli* (kilometer 公里)	M_3
	Variable	e.g., *di* (drop 滴), *dai* (bag 袋), *bei* (cup 杯)	M_4

M_2 and M_4 are thus similar in that their values are vague and not fixed. The difference is that the vague value of a M_2 is numerical, while that of a M_4 is not. For example, the M_2 *cuo* ‘small gang’ must take a count noun, e.g., *yi cuo qiangdao* ‘a small gang of bandits’, and must have a numerical value larger than one. Likewise, the M_2 *bang* ‘gang’ in *yi bang qiangdao* ‘a gang of bandits’ must also have a numerical value larger than two. However, the typical number implied by *bang* ‘gang’ is larger than that implied by *cuo* ‘small gang’. In contrast to M_2, the vague values denoted by M_4 are not numerical and may be length, area, weight, volume, time, etc. For example, the M4 *di* ‘drop’, as in *yi di shui* ‘a drop of water’, refers to a vague volume of water in the shape of a teardrop. The M_4 *tan* ‘puddle’, as in *yi tan shui* ‘a puddle of water', though likewise referring to a vague volume of water, but in a random shape, has an implied value much bigger than that implied by *di* 'drop'. Note, crucially, that the English counterparts of M_2 and M_4 are clearly nouns in terms of syntactic category. Yet, in Chinese, M_2 and M_4 are part of a distinctive syntactic category C/M, or numeral classifiers [8]. It is controversial whether the processing of Chinese numeral classifiers involves magnitude. The aim of our study was to address this issue.

However, as attractive as this theory may be, empirical evidence of the mathematical function of C/Ms was lacking. Thus, the aim of this study was to conduct a psycholinguistic experiment to examine whether participants process C/Ms based on their mathematical values as this multiplicative theory of C/M predicted they would. More specifically, the theory predicted that the difference between C/Ms with fixed values, i.e., C, M_1, and M_3, and those with non-fixed vague values, i.e., M_2 and M_4, would be more prominent than the difference between C/Ms with numerical values, i.e., C, M_1, and M_2, and those with non-numerical values, i.e., M_3 and M_4, for the simple reason that a $M_{2/4}$ with a vague value cannot be coerced into having a rigid fixed value without an appropriate and robust discourse context, while a $M_{3/4}$ with an inherent non-numerical value can be quite easily converted numerically to a smaller unit, e.g., *one kilo* into *one thousand grams*.

The most relevant previous study is Cui et al. [10], where a functional magnetic resonance imaging (fMRI) experiment compared the brain activities of processing classifiers with those of processing tool nouns, numbers, and dot arrays. Tool nouns are non-quantity words which refer to concrete objects used as tools, utensils, or instruments, e.g., *liandao* (sickle) and *laba* (trumpet). A semantic distance comparison task was used, where participants chose from two items the one that was semantically closer to the target item. For example, the target *fuzi* (axe) was presented on the top of the screen and participants had to judge whether *liandao* (sickle) or *niezi* (tweezers) which were displayed at the bottom of the screen was semantically closer to the target word *fuzi* (axe). Greater activation was found in the left middle frontal gyrus (MTG) and the left inferior frontal gyrus (IFG) instead of the right intraparietal sulcus (IPS) for processing classifiers and tool nouns than numbers and dot arrays. This result is rather unexpected under Her's [8] theory, which predicts that brain activities of processing C/Ms should be more similar to those of processing numbers and dot arrays than to those of processing tool nouns. Given that some C/Ms (see Table 2), numbers, and dot arrays represent numerical magnitude, we expected that the processing of C/Ms, but not that of tool nouns, would elicit higher activations in the right IPS, which plays an important role in representation of numerical magnitude [11-12].

One possible critical reason why Cui et al. [10] did not find the IPS more activated for processing C/Ms than processing tool nouns is that their experimental materials of the so-called "classifiers" mixed up Cs and Ms and thus no distinction was made between Cs and Ms. Yet, as reviewed above, linguistic studies suggested that Cs differ significantly from Ms [e.g., 5-6]. Furthermore, the taxonomy proposed by Her and Wu [9] also categorizes the mathematical values of C/Ms along the dimension of [fixed vs. variable]. Presumably, C/Ms with a fixed value may be related to exact representation of numbers, while C/Ms that encode a variable value may be associated with approximation. We hypothesized that participants would choose the C/M option that had the same or closer value as that of the target C/M, when the values in question were all fixed. However, it was unclear how participants would process C/Ms with variable values.

Note also that Cui et al. [10] did not use complete [Num X N] phrases, e.g. *yi zhang haibao* (1 $C_{\text{-flat}}$ poster, one poster), as stimuli in the semantic distance comparison task. Rather, they used [Num X] phrases, e.g. *yi zhang* (1 $C_{\text{- flat}}$), in their study. Thus, the semantic context was not strictly confined in their study. Therefore, we replicated the paradigm by Cui et al. [10] but used a more appropriate set of stimuli, i.e. [Num X N] phrases, e.g. *yi zhang haibao* (1 $C_{\text{- flat}}$ poster, one poster), to examine whether C/Ms were processed based on mathematical values.

We hypothesized that, first, participants would compare the mathematical values the C/Ms encode and select the one with the same or closer value to the target C/M, and, second, the accuracy of C/Ms with fixed values to be higher than that of C/Ms with variable values.

Method

Participants

Twenty individuals (16 females, 4 males, ages 20-28, mean age = 22.6 ± 2.06) were recruited from National Chengchi University. Participants were right-handed, had normal or corrected-to-normal vision. Their first language is Mandarin. They gave written informed consent to the study approved by the Research Ethics Committee of National Taiwan University and received NT$100.

Stimuli and experimental design

We conducted a 2 × 2 within-subject design. The two independent variables were the numerical type (numerical: C, M_1, and M_2 vs. non-numerical:M_3 and M_4) and mathematical value type (fixed value: C, M_1, and M_3 vs. variable value: M_2 and M_4). There were thirteen C/Ms for each condition (see S1 Table). Each C/M repeated twice as the target C/M. For each trial, another two C/Ms from the same condition were selected to be paired with the target C/M. When three C/Ms phrases were paired together for a trial, two experimenters produced a reasonable noun for this set of C/Ms to confine the semantic contexts. One experimenter created these [Num X N] phrases and the other experimenter checked if all phrases were clear and understandable. For the phrases that were unclear, the two experimenter discussed and came up with another noun that better fit the set of C/Ms. The nouns were unrepeated throughout the experiment. Consequently, there were 104 sets of C/M phrases in total. Each condition included 26 trials. The target C/M phrases were composed of the number 1 and a C/M. The answer and distractor C/M phrases included the number 1, a C/M, and a noun. The answer and distractor C/M phrases differed in the C/M. The numeral enabled participants to process the C/M as a C/M, not a noun. By designing the answer/distractor phrase as a minimal pair, we strictly confined the semantic context for the C/M (Table 3). We recorded responses and reaction times (RT).

(Insert Table 3 roughly here)

Table 3. Structure of the experimental stimuli with a sample set for each condition.

Stimuli type	Value type	Target C/M	C/M Option 1	C/M Option 2
Numerical	Fixed	一副 *yi fu* one set of (M_1, n = 2)	**一對耳環** ***yi dui erhuan*** **one pair of earrings** **(M_1, n = 2)**	一只耳環 *yi zhi erhuan* one earring (C, n = 1)
	Variable	一隊 *yi dui* one team of (M_2, n > 1)	一群殺手 *yi qun shashou* one group of killers (M_2, n > 1)	一幫殺手 *yi bang shashou* one gang of killers (M_2, n > 1)
Non-numerical	Fixed	一公斤 *yi gongjin* one kilo of (M_3)	**一磅橡膠** ***yi bang xiangjiao*** **one pound of rubber** (M_3)	一噸橡膠 *yi dun xiangjiao* one ton of rubber (M_3)
	Variable	一杯 *yi bei* one cup of (M_4)	一罐咖啡 *yi guan kafei* one can of coffee (M_4)	一瓶咖啡 *yi ping kafei* one bottle of coffee (M_4)

Table legend: There were 26 trials for each condition in the experiment. In each trial, there was a target C/M phrase, an answer C/M phrase, and a distractor C/M phrase. The target C/M phrases were composed of the number 1 and a C/M. The answer and distractor C/M phrases formed a minimal pair which included the number 1, a C/M, and a noun. The answer C/M phrases were indicated in bold in this table. Note that they were *not* presented in bold in the experiment.

Procedure

There were eight practice trials to ensure that participants fully understood the task. In each trial, participants saw three C/M phrases on the screen at the positions of the three end points of a triangle (Fig 1). They had to perform a semantic distance comparison task: which one of the two C/M phrases at the bottom was semantically closer to the target C/M phrase at the top. The positions of the answers and the distractors were randomized. Participants had up to 8 seconds (s) to respond. The inter-trial interval was 500 milliseconds (ms). There were 104 trials in total; each condition included 26 trials. The order of the trials was randomized. Right after the experiment, participants filled in a questionnaire to indicate their subjective mathematical values of the M_2 and M_4 used in the experiment. The questionnaire listed all C/Ms that appeared in the experiment in the form of [one C/M]. Take *yi fu* (one set of) for example, participants had to fill in the blank *yue* " " *ge* (around " " C) to indicate their subjective mathematical value. For non-numerical M_{3-4}, participants had to fill in the blank to indicate around how much centimeter (length), square meter (area), gram (weight), and milliliter (volume) they think the M_{3-4} represented for different types of M_{3-4} respectively. For example, when participants saw *yi bei* (one cup of), they had to fill in the blank *yue* " " *haosheng* (around " " milliliter) to indicate their subjective mathematical value of *yi bei* (one cup of).

(Insert Figure 1 roughly here)

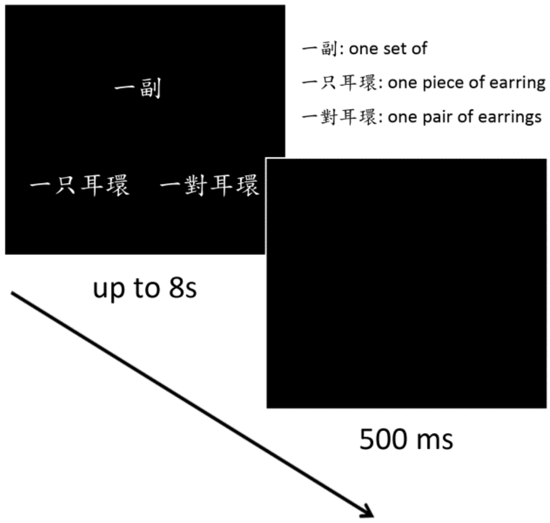

Fig 1. The experimental procedure. In each trial, participants saw three C/M phrases on the screen. They had to choose between the two C/M phrases at the bottom the one that was semantically closer to the target C/M phrase on the top. The C/M options were composed of minimal pairs which included an identical numeral, a classifier or a measure word, and an identical noun.

Data analysis

The responses and RT were analysed in a two-way (numerical/ non-numerical × fixed/ variable values) repeated measures ANOVA. IBM SPSS 20.0 was used for the statistical analysis with the α value set at .05. Post-hoc analyses of the simple main effects were made by means of t-tests applying Bonferroni's correction for multiple comparisons. We calculated the accuracy of M_2 and M_4 based on the subjective mathematical values reported by the participants individually (see S1 Table for the descriptive statistic reports). For each participant, we determined the correct answer of each trial according to the subjective mathematical values that they reported. Take the sample set of M_2 in Table 3 for example, if a participant reported that his/her subjective mathematical values of *yi dui* (one team of), *yi qun* (one group of), and *yi bang* (one gang of) were 10, 20, and 30, respectively, the answer of this trial for this participant would be *yi qun shashou* (one group of killers) instead of *yi bang shashou* (one gang of killers), as 20 is closer to 10 than 30 is.

Results

The mean (and standard deviation, SD) of accuracy and RT are shown in Table 4.

(Insert Table 4 roughly here)

Table 4. The mean (and standard deviation) of accuracy and reaction times (RT) in Experiment

	Numerical C/M	Non-numerical C/M
Fixed value		
Accuracy (proportion correct)	0.734 (0.086)	0.744 (0.079)
RT (s)	2.446 (0.634)	2.511 (0.585)
Variable value		
Accuracy (proportion correct)	0.568 (0.130)	0.583 (0.124)
RT (s)	2.794 (0.708)	2.886 (0.666)

Accuracy

The significant main effect of the numerical types was not significant, $F_{(1,19)} = .227$, $p = .639$, such that the accuracy of the numerical C, M_1, and M_2 and that of the non-numerical M_3 and M_4 were not significantly different. However, there was a significant main effect of the mathematical value types, such that the accuracy of C/Ms with fixed values was significantly higher than those with variable values, $F_{(1,19)} = 68.298$, $p < .001$. The accuracy of C and M_1 was significantly higher than that of M_2 ($p < .001$), and the accuracy of M_3 was significantly higher than that of M_4 ($p < .001$). There was no significant interaction effect between the numerical types and the mathematical value types, $F_{(1,19)} = .013$, $p = .91$ (Table 4).

Reaction times

The significant main effect of the numerical types was not significant, $F_{(1,19)} = 2.098$, $p = .164$, such that the RT of numerical C/$M_{1\text{-}2}$ and that of non-numerical $M_{3\text{-}4}$ were not significantly different. However, the mathematical value types displayed a significant main effect, $F_{(1,19)} = 37.726$, $p < .001$, such that the participants responded faster while processing the C/M with fixed values compared with the C/M with variable values. The RT of C/M_1 was significantly shorter than M_2 (p = .001), and the RT of M_3 was significantly shorter than M_4 (p < .001). There was no interaction between the numerical types and the mathematical value types, $F_{(1,19)} = .068$, $p = .797$ (Table 4). In general, the pattern of reaction times under the four conditions was consistent with that of accuracy. The higher the accuracy, the shorter the RT.

Discussion

The results showed that participants made semantic judgments based on the mathematical values of C/Ms, numerical or not, when the values were fixed rather than variable. They responded faster in processing C/Ms with a fixed value than a variable value. The mean accuracy of M_2 (0.568) and M_4 (0.583) with variable values was relatively low, even though the accuracy was calculated individually dependent on the subjective mathematical values reported by each participant. This was consistent with our prediction that C/Ms with fixed values are mathematically comparable, while C/Ms with variable values are too vague to be comparable.

It is still possible that participants represented a rough value that M_2 or M_4 encode and tried to compare. However, because of the variability of the values they encode, participants may not be able to represent these variable values exactly the same way every time. In other words, the subjective mathematical values may have fluctuated between the time of performing the semantic distance comparison task and filling in the post-experimental questionnaire. To modify this limitation in the current study, we suggest future studies ask participants to report their subjective mathematical values immediately after each trial.

It is worth noting that the mean subjective mathematical value of M_2 ranged only from 5 to 18 and the variance was rather small (see S1 Table). This may make choosing between the two options of C/Ms difficult and result in fifty percent of chance to choose one of the two options of C/Ms. Even if the participants represented M_2 as a mathematical value, the closeness of the two options of C/Ms may be too competitive to make a distinct difference. Furthermore, although the mean subjective mathematical value of M_4 varied to a greater extent than M_2 did, the variance was large. This indicates that there was a large individual difference of the subjective mathematical values of M_4s. Future studies are suggested to use a complete sentence or story to confine the context to better control the semantic distance of C/Ms. Since behavioral responses could not answer whether participants processed C/Ms with variable values mathematically, future studies can further investigate the quantity processing of C/Ms that encode variable values using fMRI by examining the brain activations related to numerical representation such as the IPS [11-12].

One may argue that the quantification of *a gang of* might be different for killers and for hooligans and the quantification of *a litter of* might be different for mice than for cats. This indeed may be true for M_2 and M_4, which have non-fixed variable values. Yet, this possible noun-contingency effect was not a factor in the experiment, as all minimal pairs of [one $M_{2/4}$ N] have exactly the same N. One may also suspect that the discriminability of these pairs might vary over nouns, e.g., the difference between *a team of salespeople* and *a gang of salespeople* might be different in not only magnitude but sign from the difference between *a team of killers* and *a gang of killers*. Again, this possible effect was not a factor in the experiment as no such cross-pair comparison was elicited and only within-pair comparison was required.

Not surprisingly, there was no significant difference between numerical and non-numerical C/Ms. One of the reasons may be that we adopted the semantic distance comparison task in this experiment. It is likely that participants converted the non-numerical C/M into the same unit to make a comparison. For example, when participants had to choose between *yi bang* (a pound) and *yi gongjin* (one kilo), they represented them as 453 grams and 1000 grams, whether exactly or approximately, to make the judgment. In other words, it was possible that due to the nature of the semantic distance comparison task which may require accurate quantity comparison, participants preferred representing C/Ms as a numerical value to perform the task in the current study. This may explain why we did not observe significant difference between numerical and non-numerical C/Ms. We suggest future studies use other tasks to further investigate whether the cognitive processing of numerical and non-numerical C/Ms are similar in spite of experimental paradigms. Future study may also use neuroimaging techniques to examine whether numerical and non-numerical C/Ms engage in a similar neural network.

Partially consistent with our hypothesis that C/Ms encode mathematical values, we found that participants did represent and compared the mathematical values of C/Ms with fixed values. If participants did not process them based on their mathematical values, the accuracy of numerical C/Ms would not have been above the chance level. However, it remains unclear how participants processed the C/Ms with variable values. Moreover, it is unknown whether participants processed non-numerical C/Ms in a numerical form to perform the semantic distance comparison task. Therefore, future studies are needed to further examine the cognitive processing of non-numerical C/Ms using other tasks. In general, our findings, in part, corroborated Her's [8] mathematical theory of C/M that C/Ms encode mathematical values by providing behavioral evidence of C/Ms with fixed mathematical values.

To our knowledge, this study was the first study providing evidence that showed Chinese C/Ms encode mathematical values. Participants represented and compared fixed mathematical values of C/Ms to make a semantic judgment. This psychological finding laid an empirical foundation supporting Her's [8] mathematical theory, where C and M converge as the multiplicand of Num but diverge in terms of their respective value: $C = 1$, $M \neq 1$. We verified the notion that Cs encode 1 and Ms encode certain other mathematical values by showing that participants chose the C/M that had the same or closer value to the target C/M when the mathematical values were fixed in the semantic distance comparison task. Future psycholinguistic and neurolinguistic studies should further investigate whether the mathematical relation between Num and C/M is multiplication. In sum, findings in the current study implied that the linguistic system of C/Ms might influence magnitude cognition.

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Competing interests

We declare that there is not any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, our work.

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Supporting information

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185047#sec011

S1 Table. Stimuli used in the experiment. The word frequency was obtained from the Digital Resources Center for Global Chinese Language Teaching and Learning by Cheng et al. [13].

Year 2

Neural Correlates of Quantity Processing of Chinese Numeral Classifiers

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Introduction

In a classifier language like Chinese an additional element is essential when a noun (N) is quantified by a numeral (Num). This additional element is known as a numeral classifier. As shown in Table 1, numeral classifiers come in two varieties, sortal classifiers (C) and mensural classifiers (M). Note that there are a number of alternative names for the two, e.g., classifiers and measure words, classifiers and massifiers, count-classifiers and mass-classifiers, etc. Suffice to say that making the distinction within the category of numeral classifiers is far more important than the particular terms used. We will thus use the abbreviations C and M for this distinction and C/M for the category of numeral classifiers.

Table 1

Examples of sortal and mensural classifiers

Sortal Classifiers (C)	Mensural Classifiers (M)
三 本 雜誌	三 箱 雜誌
san ben zazhi 3 C magazine '3 magazines'	*san xiang zazhi* 3 M-box magazine '3 boxes of magazines'
三 個 蘋果	三 公斤 蘋果
san ge pingguo 3 C apple '3 apples'	*san gongjin pingguo* 3 M-kilo apple '3 kilos of apples'

Though it has been controversial whether C and M belong to the same grammatical category, C and M clearly converge syntactically as they always appear in the same grammatical position and are mutually exclusive (1-3), but C and M diverge semantically in the sense that Cs qualify the noun but Ms quantify the noun (4, 5). Her (6) indicated that in the nominal phrase [Num C/M N], C is semantically redundant but M is semantically substantive, and proposed an innovative interpretation in terms of the mathematical relation between Num and C/M. The precise formulation he offered is: **[Num X N] = [[Num × X] N], where X = C if and only if X = 1, otherwise X = M** (6). Given the multiplicative function between Num and C/M, **i.e., [Num × C/M]**, C and M converge as multiplicands but diverge in terms of their respective values, i.e., C = 1, M ≠ 1.

Her and Wu (7) further classified Ms into four subcategories according to the types of mathematical values they encode (Table 2). While M_1 and M_2 both encode numerical values, the former has fixed values and the latter does not. Likewise, M_3 and M_4 both encode non-numerical values, but the former has fixed values and the latter does not. Thus, C, M_1 and M_3 encode fixed values, while M_2 and M_4 do not.

Table 2

Types of mathematical values denoted by C/Ms

Numerical	Fixed	**n=1** e.g., *ben* (本), *ke* (顆), *tiao* (條), *zhi* (隻)	C
		n=2 e.g., *duei* (pair 對); **n=12** e.g., *da* (dozen 打)	M_1
	Variable	**n>1** e.g., *pai* (row 排), *zu* (group 組), *die* (stack 疊)	M_2
Non-numerical	Fixed	e.g., *gongjin* (kilogram 公斤), *gongli* (kilometer 公里)	M_3
	Variable	e.g.,*chi* (spoon 匙), *dai* (bag 袋), *bei* (cup 杯)	M_4

While Her's (6) multiplicative theory of C/M is based on the premise that numerals and C/Ms are closely related, it is still controversial whether language and mathematics belong to two independent domains or are related in some aspects. While the two seem to involve distinct cognitive abilities, both represent concepts by symbols (e.g., number words, Arabic numbers, and arithmetic operations, etc.). Psychologists have thus investigated whether the form of neural representation of number is notation-independent (8, 9) or notation-specific (10).

Neuropsychological studies (11-13) and neuroimaging studies (14, 15) tapped into this question by examining the neural basis in processing number words, quantifiers, classifiers, and numbers. In Butterworth et al. (11), a semantic dementia patient, who had left temporal lobe atrophy, encountered severe impairment in linguistic abilities and general knowledge while preserving intact mathematical abilities. This patient performed remarkably well at reading and spelling number words, whereas he was unable to read or spell non-number words. Cappelletti et al. (12) also described a semantic dementia patient who selectively possessed intact understanding of quantifiers (e.g., *many*, *a few*) only. Likewise, this patient showed the ability in the comprehension of numerical knowledge but not linguistic concepts. These results suggested that the semantic processing of numerical knowledge is functionally and neuroanatomically distinct from non-numerical knowledge and is notation-independent.

Nevertheless, inconsistent results are found in other studies, e.g., Cipolotti et al. (13) and Wei et al. (15). Cipolotti et al. (13) reported an acalculic patient who was able to read letters, words, and number words but not Arabic numbers, suggesting that number processing is notation-dependent. Notably, Cipolotti et al. (13) also found that the patient’s knowledge of cardinal value of Arabic numbers was intact in magnitude comparison tasks. This suggested that although the number processing is notation-dependent, the processing of semantic quantity may not be notation-dependent. Wei et al. (15) compared the brain activations of semantic processing of quantifiers (e.g., frequency adverbs and quantity pronouns), words (e.g., animal names), Arabic numbers, and dot arrays with functional magnetic resonance imaging (fMRI). They found that processing of numbers and dot arrays activated more in the right intraparietal sulcus (IPS), which plays an important role in representation of numerical magnitude (16, 17), whereas the processing of quantifiers elicited greater activations in the left middle temporal gyrus (MTG) and the left inferior frontal gyrus (IFG) that are usually associated with general semantic processing (18).

Similar results were obtained from the very first fMRI study on quantity processing of Chinese numeral classifiers by Cui et al. (14).[1] They compared the processing of classifiers with those of tool nouns, numbers, and dot arrays in a semantic distance comparison task, where participants had to judge which one of the two items was semantically closer to the target item. They reported that classifiers, tool nouns, numbers, and dot arrays commonly activated in the right IFG, right angular gyrus, right supplementary motor area, right precentral gyrus, left insula, left cerebellum, and bilateral lenticular nucleus. They found that classifiers and tool nouns elicited greater activation in the left IFG and the left MTG than numbers and dot arrays. They did not find that classifiers elicited more activations than tool nouns in the IPS, which plays an important role in processing and representation of numerical magnitude (16, 17). The aim of our study is thus to reexamine the neural correlates of quantity processing of Chinese numeral classifiers.

One possible critical reason why Cui et al. (2013) did not find the IPS more activated for processing classifiers than tool nouns may be that they did not make the crucial distinction between C and M. Nor did they make the distinction between numerical and non-numerical C/Ms. The term "classifier" they used referred to both C and M in their study. As reviewed above, linguistic studies suggest that Cs differ significantly from Ms and Ms can be further classified, according to Her and Wu (7), into four categories along two dimensions: numerical vs. non-numerical and fixed vs. variable (Table 2). The processing of numerical and non-numerical C/Ms may vary significantly.

[1] While non-classifier languages have no syntactic category of C/M, the semantic concept of Ms exists cross-linguistically. English, and other non-classifier languages, may thus have words of measure such as *pair*, *group*, and *kilo* that are nouns syntactically. Numerals, on the other hand, are available in nearly all languages, and are considered part of quantifiers, e.g., *a lot*, *many*, and *few*. However, grammatical number markers, e.g., the suffix /-s/ in English, and sortal classifiers, or Cs, are largely mutually exclusive in a noun phrase, in the few languages that employ both. This fact has led to a controversial view that C and grammatical number belong to the same syntactic category. Relevant to our study is the fact that C/Ms, numerals, quantifiers, and plural markers all carry quantity information.

Also, Cui et al. (14) did not explain how they selected and arranged the stimuli for each trial in the semantic distance comparison task. Thus, they may not have controlled the potential confounding effect of the semantic attributes of C/Ms, which may have been another reason why they did not find the IPS more activated for processing C/Ms than processing tool nouns. To be more specific, Chinese Cs are based on a range of semantic attributes such as human, animacy, shape, function, etc. Cs thus function as a profiler in highlighting an inherent semantic feature of the noun (6, 19). For example, there are at least three different Cs that are compatible with the noun *yu* (fish): *zhi* emphasizes the feature of animacy, *tiao* highlights the long shape, and *wei* profiles the tail (6). Accordingly, it is possible that, aside from the mathematical values of C/Ms, the semantic attributes of C/Ms play a role in processing C/Ms. Thus, that the confounding factor of C/M's semantic attributes was not controlled in the fMRI study by Cui et al. (14) may also explain the higher activation in brain regions that are related with general semantic processing such as the left IFG and the left MTG.

The purpose of our study was to replicate the fMRI experiment by Cui et al. (14), but with a modified paradigm which controlled the confounding factors. We expected to see that C/Ms and numbers induce more activation in the IPS compared with tool nouns.

Prior to the fMRI experiment, we conducted two behavioral experiments with semantic distance comparison tasks to clarify how the variables mentioned above influenced the processing of C/Ms. In the first experiment, we examined how semantic attributes of C/Ms influenced processing. Participants had to decide which one of the two C/M phrases at the bottom of the screen was semantically closer to the target C/M phrase on top. Results showed that participants preferred the one with comparable semantic attributes over the one with a closer mathematical value. This suggested that a C/M's semantic attributes affected processing, and this thus was likely a confounding factor not controlled in the fMRI study by Cui et al. (14).

Therefore, we conducted a second experiment and controlled the semantic attributes of C/M by using minimal pairs as stimuli (20). An example of a minimal pair is *yi qun shashou* (one group of killers) and *yi bang shashou* (one gang of killers), where the identical human noun *shashou* (killer) confines the semantic attributes of the two Ms in the two nominal phrases, which thus differ minimally only in terms of the mathematical values the two Ms encode. Consequently, the judgment whether *yi qun shashou* (one group of killers, $n > 1$) or *yi bang shashou* (one gang of killers, $n > 1$) is semantically closer to *yi dui shashou* (one team of killers, $n > 1$) must be based on this variable alone. For example, if a participant reported that his/her subjective mathematical values of *yi dui* (one team of), *yi qun* (one group of), and *yi bang* (one gang of) were 10, 20, and 30, respectively, the correct answer of this trial for this participant would be *yi qun shashou* (one group of killers) instead of *yi bang shashou* (one gang of killers), as 20 is closer to 10 than 30 is. Results showed that participants performed better for C/Ms with fixed values than those with variable values (20).

Therefore, in order to better examine the neural correlates of C/Ms in the fMRI study, we developed a modified paradigm based on these behavioral findings and used minimal pairs of phrases with C/Ms of fixed values. Given previous findings that the IPS represented number independent of notations (8, 16), we expected to find greater activations in the IPS for processing C/Ms than tool nouns by adopting our modified paradigm.

Method

Participants

Twenty-six native speakers of Mandarin (14 males, mean age = 23.23 ± 2.35 years) were recruited from National Chengchi University. All participants were right-handed. They had normal or corrected-to-normal vision and had no history of neurological or psychiatric disorders or contraindications to MRI. Before the experiment started, they gave written informed consent to the study approved by the Research Ethics Committee of National Taiwan University.

Stimuli and Materials

We conducted a within-subject design and manipulated two variables. The two independent variables were comparison (C/Ms vs. tool noun) and C/M type (numerical vs. non-numerical). The four main experimental conditions were C/M comparison with numerical stimuli, C/M comparison with non-numerical stimuli, tool noun comparison with numerical stimuli, and tool noun comparison with non-numerical stimuli (see Figure 1 gray part). The nominal phrases consisted of a numeral (the number “one”), a C or M, and a tool noun. Including the numeral in the phrase enabled participants to process the C/M in the phrase correctly as C/M instead of other meanings.

There were five other conditions: baseline, numbers, dots, number words, and tool nouns. We modified the baseline condition in Cui et al. (14), which was the rest (fixation). In this study, the baseline condition contained three identical nominal phrases for each trial. In this case, participants still had to process the stimuli that were visually as complicated as the ones in the main four experimental conditions (see Appendix A for all experimental stimuli). Consequently, we could examine the brain activations involved in processing C/M or tool nouns by contrasting the four main experimental conditions against the baseline condition. Following the paradigm by Cui et al. (14), we further included conditions of numbers, dots, number words, and tool nouns to investigate the neural correlates that commonly activated during number processing (C/M comparison, numbers, dots, number words) and semantic processing (tool noun comparison and tool nouns).

(Insert Figure 1 about here)

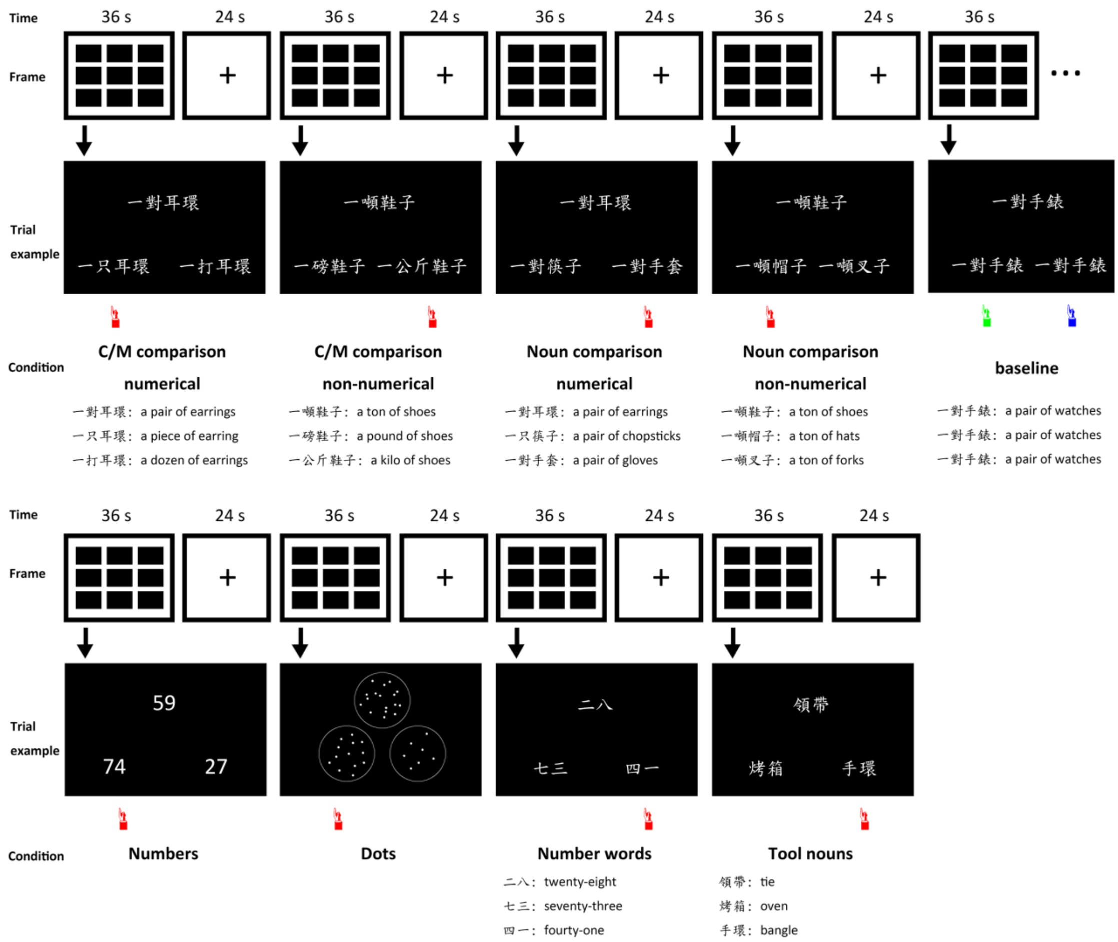

Figure 1. The experimental procedure and sample trials of each condition in this study. The four main experimental conditions, varying in comparison (C/Ms vs. tool nouns) and C/M type (numerical vs. non-numerical), were shown in the gray part. The other five conditions were baseline, numbers, dots, number words, and tool nouns. There were 3 runs in total; each run had 9 blocks. Each block was 36 s followed by a 24-s rest. Each condition had 9 trials per block. For each trial, participants had to judge which one of the two items at the bottom was semantically closer to the target item. For the conditions of numbers, dots, or number words, participants were asked to judge which one of the bottom items had a closer quantity with the target item. The answer item was indicated with the hand icon. For the baseline condition, in which the three phrases were identical, half of the participants were told to press button 1 (left) and the other half were told to press button 2 (right) to show that they remain concentrated in the scanner.

The number of strokes, frequency of C/Ms, and frequency of nouns were carefully matched among the four main experimental conditions and the baseline condition (Appendix B). The word frequency was obtained from the Digital Resources Center for Global Chinese Language Teaching and Learning (21).

For the conditions of C/M comparison, numbers, dots, and number words, the number of the target item was larger or equal to the answer for one third of the trials; the number of the target item was in the middle of the answer and the distractor for one third of the trials; the number of the target item was smaller or equal to the answer for the rest one third of trials. For the conditions of numbers, dots, and number words, the number of the stimuli ranged from 7 to 99.

For the conditions of tool noun comparison and tool nouns, the answer was an item that fell into the same category as the target item. Tool nouns were selected from a set of tool nouns that were categorized into seven categories: constructional material, stationery, clothing and accessories, kitchenware and utensils, weapons, sporting goods, and daily essentials. The conditions of noun comparison and the tool noun condition were composed of two different sets.

Procedure

We conducted a block design. There were 3 runs in total; each run had 9 blocks. Each block was 36 s followed by a 24-s rest. Each condition had 9 trials per block. In each trial, stimuli displayed for 3.5 s with a 0.5 s inter-trial interval. The order of blocks and trials were randomized. Before scanning, participants completed 18 practice trials and made sure that they were clear about the procedure.

In each trial, participants saw three items on the screen and were asked to judge which one of the two items at the bottom was semantically closer to the target item at the top. Accuracy and speed were both emphasized. If they saw numbers, dots, or number words, they were asked to judge which one of the bottom items had a closer quantity with the target item. They pressed button 1 or 2 to choose the stimuli on the left or right, respectively. They were also told that in order to ensure that they remain focused in the scanner, sometimes they might see three identical items. In this case, i.e. the baseline condition, half of the participants were told to press button 1, whereas the other half were told to press button 2 (Figure 1).

fMRI Data Acquisition

MRI images were collected using a 32-channel head coil in a 3T scanner (Skyra, Siemens Medical Solutions, Erlangen, Germany). A T2*-weighted gradient-echo echo planar imaging (EPI) sequence was used for fMRI scanning, with a 4 mm slice thickness, 200 × 200 mm^2 field of view (FOV), 90° flip angle, 32 axial slices, 2000 ms repetition time (TR), and 30 ms echo time (TE). The anatomical, T1-weighted high-resolution image (1 × 1 × 1 mm^3) was acquired using a standard MPRAGE sequence, with a 7° flip angle, 2530 ms TR, 3.3 ms TE and 1,100 ms inversion time (TI).

Statistical Analysis of the fMRI Data

Preprocessing and statistical analysis of brain images were performed using a statistical parametric mapping 8 (SPM8; Wellcome Trust Center for Neuroimaging, London, UK) software package. The functional images of each participant were corrected for slice timing and head motion and then co-registered to the participant's segmented gray matter image. Next, the images were normalized to the standard Montreal Neurological Institute (MNI) standard space and spatially smoothed by convolution using an 8 mm full width at half maximum Gaussian kernel.

We conducted two random-effect whole-brain analyses. One was a full factorial 2 (C/M vs. noun comparison) by 2 (numerical vs. non-numerical CM) ANOVA with images from the individual-level fixed-effect analysis modelling each condition in contrast to the baseline. Then, we conducted contrast analyses for the four main conditions. The other was a one-way ANOVA with images of 9 conditions relative to rest. Consequently, we ran three conjunction analyses to examine the brain regions that co-activate for the four main conditions, five conditions of number processing, and three conditions of semantic processing. The threshold of the statistical maps was at a whole brain voxel-wise intensity of $p_{FWE\text{-}corr} < .05$ (Family-wise error correction). The resulting regions of activation were characterized in terms of their peak voxels in the MNI coordinate space and specified with the automated anatomical labeling.

Results

Participants' exclusion for data analyses

Among the 26 participants, two participants were excluded from data analysis because of data loss and three participants were excluded due to excessive head movement (i.e., whose overall motion was more than 3 mm across the runs or more than 1.5 mm motion between adjacent functional volumes).

Contrast analyses

Figure 2A and Table 3 show the results from contrast analyses. First, C/M comparison elicited higher activation than noun comparison in the bilateral inferior parietal lobule (IPL) including the IPS, right superior frontal gyrus (SFG), bilateral middle frontal gyrus (MFG), right medial frontal gyrus (mFG), right middle temporal gyrus (MTG), and left lingual gyrus. However, on the other hand, noun comparison did not elicit significantly higher activation than C/M comparison. In addition, the contrast analyses between numerical C+M_1 and non-numerical M_3 did not reveal any significant activation.

(Insert Figure 2 about here)

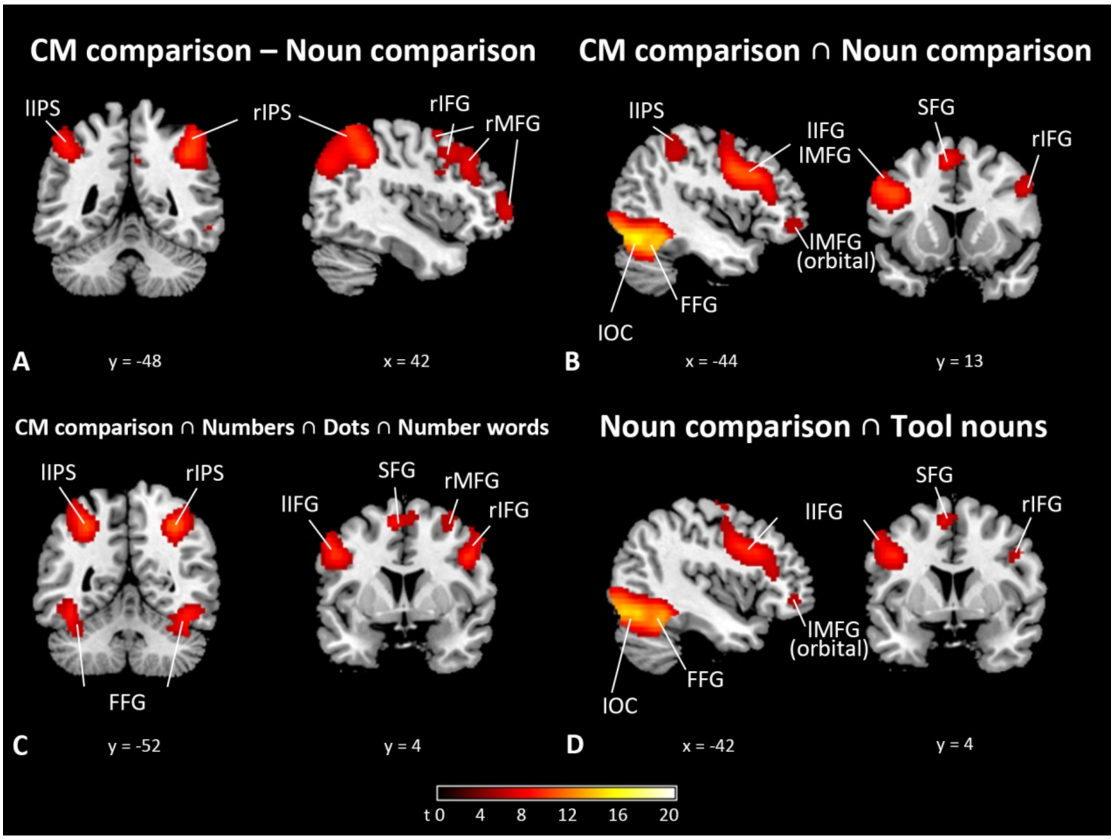

Figure 2. Brain activations from the contrast analysis and conjunction analysis

Table 3

Brain activation for contrast analysis between four main conditions, relative to baseline. ($p_{FWE\text{-}corr}$ < .05; BA, Brodmann's area)

Hemisphere	Brain regions	Peak MNI x	y	z	t-Value	Cluster size
CM comparison – Tool noun comparison						
Right	Inferior parietal lobule (BA 40)	42	-48	44	9.71	3928
Left	Inferior parietal lobule (BA 40)	-44	-52	50	8.69	1343
Right	Superior frontal gyrus (BA 6)	34	4	66	8.64	2544
Left	Lingual gyrus	-18	-88	-12	7.01	122
Right	Middle frontal gyrus (BA 10)	44	54	0	6.78	404
Right	Medial frontal gyrus (BA 8)	4	30	46	5.90	73
Left	Middle frontal gyrus (BA 10)	-40	56	10	5.85	98
Right	Middle temporal gyrus	56	-50	-12	5.65	21
Tool noun comparison – CM comparison						
None						
Numerical C+M_1 – Non-numerical M_3						
None						
Non-numerical M_3 – Numerical C+M_1						
None						

Conjunction analyses

Conjunction analysis of the four main conditions (processing C/M or tool nouns in classifier phrases with either a numerical C+M_1 or a non-numerical M_3) showed activation in the bilateral inferior occipital cortex (IOC) including the fusiform gyrus (FFG), bilateral inferior frontal gyrus (IFG, especially in the left hemisphere), left SFG, left MFG (orbital part), and left insula (see Figure 2B and Table 4).

Conjunction analysis of the five conditions involved in number processing (C/M comparison of numerical C+M_1, C/M comparison of non-numerical M_3, numbers, dots, and number words) showed activation in the IOC including the FFG, bilateral superior parietal lobule (SPL), bilateral inferior parietal lobule, bilateral IFG, right MFG, bilateral SFG, and bilateral insula (see Figure 2C and Table 4).

Conjunction analysis of the three conditions involved in semantic processing (two noun comparison conditions and the tool noun condition) showed activation in the bilateral occipital cortex including the FFG, bilateral superior parietal lobule, bilateral IFG (mostly in the left hemisphere), left SFG, and bilateral MFG (see Figure 2D and Table 4).

Table 4

Common brain activation for different types of conditions, relative to rest. ($p_{FWE\text{-}corr}$ < .05; BA, Brodmann's area)

Hemisphere	Brain regions	Peak MNI x	y	z	t-Value	Cluster size
CM comparison ∩ Tool noun comparison						
Left	Inferior occipital cortex	-18	-94	-12	20.68	17196
Left	Precentral gyrus (Inferior frontal gyrus, BA 9)	-44	4	34	10.33	3107
Left	Supplementary motor area (Superior frontal gyrus, BA6)	-6	6	58	8.65	533
Right	Precentral gyrus (Inferior frontal gyrus, BA 9)	48	8	34	7.54	509
Left	Middle frontal gyrus, orbital part	-44	46	-4	5.58	116
Left	Insula	-30	20	4	5.53	31
CM comparison ∩ Numbers ∩ Dots ∩ Number words						
Right	Inferior occipital cortex	34	-80	-12	14.51	18086
Right	Superior parietal lobule (BA 7)	30	-62	52	12.26	
Left	Superior parietal lobule (BA 7)	-24	-62	54	12.05	
Left	Inferior parietal lobule (BA 7, 40)	-30	-52	46	10.04	
Right	Precentral gyrus (Inferior frontal gyrus, BA 9)	50	8	34	9.75	1033
Left	Precentral gyrus (Inferior frontal gyrus, BA 9)	-48	2	36	9.04	1576
Left	Supplementary motor area (Superior frontal gyrus, BA 6)	-6	6	58	8.39	604
Right	Superior frontal gyrus (Middle frontal gyrus, BA 6)	32	-2	62	6.57	302
Right	Insula (BA 45)	32	24	6	5.93	80
Left	Insula (BA 45)	-30	24	6	5.83	64
Tool noun comparison ∩ Tool nouns						
Left	Inferior occipital cortex	-34	-86	-8	16.07	14504
Left	Superior parietal lobule	-28	-64	48	9.93	
Right	Angular gyrus (superior parietal lobule, BA 7)	30	-60	50	7.57	
Left	Precentral gyrus (Inferior frontal gyrus, BA 6, 9)	-42	4	34	8.69	2319
Left	Supplementary motor area	-6	10	56	7.48	334

	(Superior frontal gyrus)					
Right	Precentral gyrus (Inferior frontal gyrus, BA 9)	46	8	34	6.40	194
Left	Middle frontal gyrus, orbital part	-44	46	-4	5.58	92
Right	Middle frontal gyrus	44	28	22	5.39	90

Discussion

We adopted a modified paradigm that included minimal pairs of C/M with fixed mathematical values to investigate the number processing of C/M with fMRI in this study. We found that processing C/M in a semantic distance task elicited higher activations in the bilateral IPL including the IPS, right SFG, bilateral MFG, right mFG, and right MTG than processing tool nouns. As we predicted, the IPS, which has been shown to frequently engage in numerical representation, was more activated for the contrast of C/M comparison versus tool noun comparison (16, 17). Moreover, the brain activations in the IPL, SFG, and mFG largely overlapped with the brain regions that were reported in a very recent meta-analysis study of number processing (22). Sokolowski et al. (22) revealed that not only the parietal lobule but also the frontal regions play an important role in number processing. Specifically, the SFG was repeatedly activated for symbolic magnitude processing while the right mFG and cingulate gyrus were activated for non-symbolic magnitude processing. Moreover, the right SFG consistently activated during symbolic and non-symbolic number processing. Taken together, processing C/M than tool nouns engaged in frontal and parietal regions that have been suggested to associate with processing numerical information. This finding was consistent with the mathematical theory of C/M which proposed that C/M represents mathematical values (6). Although the number of strokes, frequency of C/Ms, and frequency of nouns were carefully matched among the four main experimental conditions and the baseline condition, participants still made more errors while processing C/M compared to processing tool nouns, $t_{(20)} = -3.281$, $p = .004$. One may argue that the activation in the IPS for processing C/M than tool nouns reflected higher task demand rather than magnitude representation in this study. However, it is worth noting that the bilateral IPL was found activated during number proceeising in both active and passive tasks (22). This suggests that the activation was related to magnitude processing rather than task demands. However, the function of the bilateral MFG and the rMTG for processing C/M than tool nouns remains unclear and needs further research as these regions were not typical regions that were found to be involved in number processing in the literature.

This finding was different from the finding in the study by Cui et al. (14), in which the contrast analyses between classifiers and tool nouns resulted in no significant activations. The critical reason why we observed different neural activities of processing classifiers may lie on the nature of classifiers. Chinese classifiers not only have a mathematical function but also function as a profiler. That is, Chinese classifiers not only encode the mathematical values but also highlight the inherent semantic attributes of the noun. However, Cui et al. (14) overlooked the potential possibility that participants make the semantic judgment based on C/M's semantic attributes which may have confounded their results. As found in the first behavioral experiment that we conducted before this fMRI experiment, participants chose the C/M phrase that had a similar semantic attribute to the target C/M phrase over the C/M phrase that had a similar mathematical value. Therefore, to control for the semantic attributes of C/Ms, we used minimal pairs of C/Ms as our stimuli in this experiment. Adding the same tool nouns in the nominal phrases, i.e. adopting minimal pairs, helped confine the semantic attributes of C/M. Second, we only included the C/M that encode fixed mathematical values, i.e. C, M_1, M_3, in our study whereas Cui et al. (14) also incorporated C/M with variable mathematical values, i.e. M_2 and M_4, as experimental stimuli. According to the second behavioral experiment we conducted, the accuracy for the variable mathematical value condition was only around 50% and significantly lower than the accuracy for the fixed mathematical value condition in the semantic distance comparison task (20). In other words, the underlying cognitive mechanism of processing C/M with a variable mathematical value was unclear whereas participants did show that they make semantic judgment based on mathematical values when facing C/M with fixed mathematical values. Consequently, we only included C/M with fixed mathematical in the current experiment. These amendments enabled us to purely examine the neural underpinnings of quantity processing of C/M in this study. Moreover, we further added the baseline condition, in which participants saw three identical nominal phrases that required similar perceptual processing, in this study. By contrasting the four main experimental conditions versus the baseline condition, the resulting brain activations should, at least in part, reveal magnitude representations. In sum, the brain activities for processing the quantity information that C/M encode may only appear for specific stimuli (C/M with a fixed mathematical values) under strictly controlled situation (presented in the form of minimal pairs) using stringent data analysis (contrasting against a baseline condition) as in our experiment. As C/M with fixed mathematical values may be related to exact magnitude cognition and C/M with variable mathematical values may be linked with approximate quantity conception, future research is needed to investigate the neural correlates of processing C/M with variable mathematical values to better clarify its underlying cognitive mechanism.

We speculated that another reason why Cui et al. (14) could not find the IPS more activated for classifiers than tool nouns was because that they did not differentiate numerical and non-numerical C/M. Nonetheless, our results of contrast analyses between numerical C+M_1 and non-numerical M_3 did not reveal any significant activation, suggesting that processing these two types of C/M involved similar neural activities. In our experiment, participants had to read three nominal phrases and judge which one of the two phrases was semantically closer to the target phrase. When participants made C/M comparison, they had to represent the quantity information that each C/M carry and then choose the C/M with closer mathematical value to the target C/M. Although M_3s encode non-numerical values, they may be represented as a specific numerical value to be compared in the semantic distance comparison task. For example, when participants had to compare *yi bang gang ding (*one pound of steel nails) and *yi ke gang ding* (one gram of steel nails), it is possible that they represent one pound as 453 grams to make the semantic judgment. Therefore, it is likely that due to the nature of the semantic distance comparison task in this study, representing C/M as a numerical value was one of the strategies that participants used. This may explain why we did not observe different brain activations contrasting between numerical $C+M_1$ and non-numerical M_3. Future studies are suggested to adopt other active tasks or a passive viewing paradigm to reexamine the neural correlates of numerical and non-numerical C/M and clarify if the underpinning neural activities are similar regardless of experimental paradigms.

In addition to contrast analyses, we conducted conjunction analyses. First, we showed that processing C/M and processing tool nouns commonly induced higher activations in the IOC (including FFG), bilateral IFG (especially in the left hemisphere), left SFG, left MFG (orbital part), and left insula. These regions have been found to engage in phonological and semantic processing in Chinese words (18).

Second, the conjunction analysis of number processing (C/M comparison of numerical $C+M_1$, C/M comparison of non-numerical M_3, numbers, dots, and number words) showed higher activation in the IOC including the FFG, bilateral SPL, bilateral IPL, bilateral IFG, right MFG, bilateral SFG, and bilateral insula. Replicating previous studies, the bilateral IPS were more activated for representation of numerical magnitude regardless of notations (16, 17). Our findings were also consistent with the recent meta-analysis of number processing that reported the bilateral IPL, left SPL, and the right SFG activated for both symbolic and non-symbolic number processing (22).

Third, the conjunction analysis of semantic processing (two noun comparison conditions and the tool noun condition) showed higher activation in the bilateral occipital cortex including the FFG, bilateral SPL, bilateral IFG (especially the left hemisphere), left SFG, and bilateral MFG, which was consistent with previous findings that conceptual representation engaged a distributed neural network in the brain (23, 24). Crucially, the left IFG has been shown to activate more naming tools than naming animals while participants engaged in viewing and naming these items (25).

It is worth discussing the role that the SPL play in number processing and semantic processing. Cui et al. (14) reported that the angular gyrus, which locates in the SPL, commonly activated for classifiers, tool nouns, numbers, and dot arrays. Replicating the finding by Cui et al. (14), the angular gyrus was found more activated for both number processing and semantic processing in this study. This suggests that the angular gyrus did not exclusively engage in number processing. However, the activation in the SPL for number processing (18086 voxels) was a larger cluster than the one elicited by semantic processing (14504 voxels). In particular, we found that the anterior part of the bilateral IPL, overlapping with the IPS, specifically activated for number processing than semantic processing.

Combining the literature and the findings in this study, we concluded that, linguistically, C/Ms not only highlight nouns with semantic attributes but also denote quantity with a mathematical value. This suggests that the linguistic system of C/M interactes with categorization and magnitude cognition. Moreover, our finding that processing C/Ms with fixed mathematical values elicit higher activations in frontal and parietal regions that have been shown to engage in numerical processing partially supported the mathematical theory of C/M, which suggests that C/Ms encode mathematical values (6). We suggest future studies continue to further investigate the number processing of C/M with variable mathematical values and the multiplication function of C/M to examine the theory more thoroughly. Lastly, our results of conjunction analysis of number processing verified that the IPS represents numerical magnitude independent of notations by providing neural evidence of quantity processing of C/Ms.

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Author contributions

O.-S.H. and N.-S.Y. conceived the study. O.-S.H., Y.-C.C., and N.-S.Y. designed the study. O.-S. H. and Y.-C.C. developed stimuli and Y.-C. C. collected and analyzed the data. O.-S.H. Y.-C. C. and N.-S.Y. interpreted the data. Y.-C.C. and O.-S.H. wrote the paper.

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Year 3

Quantity processing of Chinese numeral classifiers: Distance and congruity effects

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Introduction

In a classifier language such as Chinese, an additional element, known as 'numeral classifier' or simply 'classifier', is required when a noun (N) is quantified by a numeral (Num). Numeral classifiers that can appear in a classifier construction come in two subcategories, sortal classifiers (C) and mensural classifiers (M), which are also often referred to as 'classifiers' and 'measure words', respectively, among various other terms. In this paper, the overall syntactic category is referred to as 'numeral classifiers' or simply 'classifiers', abbreviated as 'C/M'. Table 1 offers examples from Chinese, where *ben* and *ke* are Cs; *xiang* (box) and *da* (dozen) are Ms.

(Insert Table 1 roughly here)

Table 1. Examples of Chinese numeral classifiers

Sortal Classifier (C)			Mensural Classifier (M)		
五	本	雜誌	五	箱	雜誌
wu	*ben*	*zazhi*	*wu*	*xiang*	*zazhi*
5	C	magazine	5	M-box	magazine
'5 magazines'			'5 boxes of magazines'		
十	顆	蘋果	十	打	蘋果
shi	*ke*	*pingguo*	*shi*	*da*	*pingguo*
10	C	apple	10	M-dozen	apple
'10 apples'			'10 dozens of apples'		

Grammarians had in fact been arguing for a long time whether C and M constitute one or two grammatical categories, until some recent studies that demonstrated convincingly that C and M converge syntactically as one single category, in that they appear in the same structural position and are mutually exclusive (1-3); yet, C and M diverge semantically, as Cs qualify the noun and contribute no additional semantic information to the noun phrase, while Ms quantify the noun and provide additional information to the noun phrase (4, 5). This convergence and divergence were further reconciled in Her's (6) mathematical account, which suggests that the relation between Num and C/M is multiplication. Under this view, C and M converge as the multiplicand, with Num as the multiplier, while they diverge in terms of their respective values: all Cs are equally and necessarily of the numerical value *1*, while an M's value can be anything that is not necessarily *1*. The precise formulation for the C/M distinction is: **[Num X N] = [[Num × X] N], where X = C if and only if**

X = 1, otherwise X = M (6). To be more specific, X, being the single category required between Num and N, is a C if its mathematical value is necessarily 1; otherwise, X is an M. For example, in *shi ke pingguo* (ten C apple), *shi* (ten) and *ke* (C) form a multiplicative unit, i.e., (10×1). Similarly, in *shi da pingguo* (ten M-dozen apple), *shi* (ten) and *da* (M-dozen) also form a multiplicative unit, i.e., (10×12). In brief, C and M both play the role of multiplicand but differ in the sense that C = 1, M ≠ 1.

Her, Chen, & Yen (7) presented a taxonomy of the mathematical values that C/Ms denote based on two dimensions: numerical vs. non-numerical and fixed vs. variable (Table 2). This taxonomy thus also serves to classify C/Ms into five subtypes accordingly. C stands on its own, whose value is numerical and fixed at 1. While M_1 and M_2 also both encode numerical values, the former denotes fixed values besides 1 and the latter does not. Likewise, M_3 and M_4 both encode non-numerical values, but the former has fixed values and the latter does not. Thus, C, M_1, and M_3 encode fixed values, while M_2 and M_4 do not.

(Insert Table 2 roughly here)

Table 2. Types of mathematical values denoted by C/Ms

Numerical	Fixed	**n = 1** e.g., *ben* (本), *ke* (顆), *tiao* (條), *zhi* (隻)	C
		n = 2 e.g., *dui* (pair 對); **n = 12** e.g., *da* (dozen 打)	M_1
	Variable	**n** > **1** e.g., *pai* (row 排), *bang* (gang 幫), *die* (stack 疊)	M_2
Non-numerical	Fixed	e.g., *gongjin* (kilogram 公斤), *gongli* (kilometer 公里)	M_3
	Variable	e.g., *di* (drop 滴), *dai* (bag 袋), *bei* (cup 杯)	M_4

Her's (6) theory implies that C/Ms play an important role in denoting mathematical values. However, empirical studies examining quantity processing of C/Ms are scarce and have shown inconsistent results. While the findings by Cui et al. (8) do not support this mathematical view of C/Ms, two more recent studies by Her et al. (7) and Her, Chen, & Yen (9) do support this view.

The study by Cui et al. (8) adopted a semantic distance comparison task using functional magnetic resonance imaging (fMRI) to investigate the neural correlates of quantity processing of Chinese numeral classifiers. Participants were asked to choose between two items the one that was semantically closer to the target item. The study compared the brain activations of processing numeral classifiers with those of processing tool nouns, numbers, and dot arrays and found that processing numeral classifiers and tool nouns induced higher activations in the left inferior frontal gyrus (IFG) and the left middle temporal gyrus (MTG) than numbers and dot arrays. Also, numeral classifiers, tool nouns, numbers, and dot arrays all activated the right IFG, right angular gyrus, right supplementary motor area, right precentral gyrus, left insula, left cerebellum, and bilateral lenticular nucleus. However, the study did not find greater activations for processing numeral classifiers than tool nouns in the right intraparietal sulcus (IPS), which has been shown to represent abstract numerical magnitude (10, 11). These findings were inconsistent with Her's (6) mathematical theory of C/M, which predicts that processing numeral classifiers would elicit greater brain activities in the right IPS compared with tool nouns, since C/Ms denote mathematical values but tool nouns do not.

Her et al. (7) replicated the semantic distance comparison paradigm in Cui et al. (8) but added the same noun to create minimal pairs of C/M phrases as experimental stimuli. By doing so, they managed to control the semantic attributes of C/Ms, which might have been a confounding factor in Cui et al. (8). Furthermore, they distinguished the subcategories of C/Ms along the two dimensions in Table 2: numerical type (numerical vs. non-numerical) and mathematical value type (fixed vs. variable) to thoroughly examine whether participants processed different types of C/Ms based on their mathematical values. They found that participants responded more accurately and faster for C/Ms with fixed values than those with variable values regardless of the numerical type. These results suggested that at least some of the Chinese C/Ms denote mathematical values and preliminarily supported Her's (6) view that C/Ms denote mathematical values.

Her et al. (9) further examined the neural correlates of C/Ms with fixed values by conducting the same task using fMRI. They found that the numeral classifiers induced greater neural activities than tool nouns in the bilateral inferior parietal lobule (IPL), middle frontal gyrus (MFG), right superior frontal gyrus (SFG), and left lingual gyrus. Moreover, they showed that processing numeral classifiers, numbers, dot arrays, and number words elicited conjunct activations in the IPS. These findings again corroborated Her's (6) mathematical theory of C/M by offering neuroimaging evidence implying that mathematical values play a role in Chinese numeral classifiers.

Given the contrasting findings regarding the quantity processing of C/Ms by previous studies, the aim of the current study was to re-examine the function of mathematical values of C/Ms by investigating whether participants represent them as numbers using another paradigm. Representation of numerical magnitude has shown two robust phenomena: the distance effect and congruity effect (12, 13). Dehaene, Dehaene-Lambertz, and Cohen (14) proposed that numbers are represented in order like a mental number line in the brain. As the mental representation of adjacent numerals (e.g. 2 and 3) may overlap to some extent, it is harder to discriminate them than distant numerals (e.g. 2 and 7) (15). Moreover, studies reported that the distance effect held not only for Arabic numerals, number words (16-18) but also dot arrays (20), angles, and lines (21). This could be interpreted in terms of Walsh's (22) view that numbers and physical stimuli may overlap and share common cognitive mechanisms in the parietal lobe. Thus, the shared representation of magnitude could cause interference between numerical value and physical size. Besner and Colheart (13) first reported that reaction times (RT) changed in accordance with the congruity between the numerical value and physical size. They found that it took shorter to compare the digits when the numerical difference between the two digits corresponds to font size difference than when they are incongruent. This demonstrated that although the physical size was irrelevant in the number comparison task, it was hard to ignore and interfered with numerical value. Henik and Tzelgov (23) further showed that numerical value also interfered with physical size. Moreover, congruent pairs facilitated RT compared with neutral trials in which the information of the irrelevant dimension was identical, whereas incongruent pairs took longer than neutral trials.

Given the two aforementioned features of number processing, in the present study we aimed to inspect how mathematical values of C/Ms function by using the number-size comparison task. Such a task is able to test whether C/Ms denote mathematical values and form a multiplication relation with the numerals ahead as Her (6) proposed. We expected to observe that C/Ms would reflect both the distance effect and the congruity effect. Firstly, smaller mathematical value difference of C/Ms would be harder to differentiate than a larger one, yielding lower accuracy and longer RT. Second, the mathematical value of C/Ms and their physical size may interfere with each other, that is, the performance of congruent trials would be facilitated and thus be more accurate and faster than neutral trials whereas it would be worsened for incongruent trials, with lower accuracy and longer RT. Third, the mathematical value of C/Ms may interact with the physical size. For example, it would be more difficult to make a comparison between the C/M phrases with close mathematical value distance plus incongruent physical size than other pairs under the mathematical value task.

Method

Participants

Twenty individuals (13 females, 7 males, ages 20-37, mean age = 22.6 ± 3.89 SD) were recruited from National Chengchi University. Participants were right-handed and had normal or corrected-to-normal vision. Their first language is Mandarin. Prior to the experiment, all participants gave written informed consent to the study. All methods were performed in accordance with the ethical principles of the Declaration of Helsinki and were approved by the Research Ethics Committee of National Taiwan University. Participants received NT$100 after finishing the experiment.

Task

Participants had to make two types of magnitude judgements on a pair of C/M phrases. In the mathematical value task, they had to choose the phrase that represented a larger quantity. On the other hand, in the physical size task, they had to select the phrase that was shown in a larger font size.

Stimuli and experimental design

We conducted a 2 (task) × 3 (congruity) × 2 (distance) within-subject design. Stimuli were C/M phrases composed of a numeral and a C or M_1 (i.e. mensural classifiers with fixed numeral values). To strictly match the word frequency and number of strokes of C/Ms, four C/Ms were used in the experiment (Table 3). The C and M_1 with matching word frequency and number of strokes were paired for a trial, that is, *sao* and *shuang* were coupled and *jian* and *dui* were put together.

(Insert Table 3 roughly here)

Table 3. Experimental Stimuli

Type	Stimuli	Word frequency	Number of strokes	Mathematical Value
C	艘 *sao* C-ship	152	15	1
	間 *jian* C-room	387	12	1
M_1	雙 *shuang* pair	153	18	2
	對 *dui* pair	369	14	2

The numerals in the C/M phrases ranged from one to nine. The distance of the mathematical value between the two phrases was manipulated as either one or three. Regarding distance = 1, the pairs were in the form of [3C $2M_1$], [5C $3M_1$], [7C $4M_1$], [5C $2M_1$], [7C $3M_1$], and [9C $4M_1$]. Take [3C $2M_1$] for example, the quantity of 3C equals to 3 (i.e., 3 × 1) whereas $2M_1$ represents 4 (i.e., 2 × 2). Therefore, the distance between 3C and $2M_1$ is 1. As for distance = 3, the pairs were [1C $2M_1$], [3C $3M_1$], [5C

$4M_1$], [5C $1M_1$], [7C $2M_1$], and [9C $3M_1$]. The phrases were presented in Kaiu.Tcc (*biao kai ti*) with three font sizes: 16, 19, and 22.

In order to balance the stimuli while reducing stimulus complexity, we followed the number-size interference paradigm by Kaufmann et al. (24). To be more specific, in the current experiment, the small mathematical value distance (distance = 1) was always combined with a large font size distance (16 and 22). The large mathematical value distance (distance = 3) was always combined with a small font size distance (19 and 22). By doing so, we could present physically the same stimuli in both tasks.

The mathematical value difference may be congruent (e.g., 3C **$2M_1$**), incongruent (e.g., **3C** $2M_1$), or non-relevant with the font size difference. For non-relevant trials (neutral condition) in the mathematical value task, the font size was always 19 (e.g. [3C $2M_1$]. For neutral trials in the physical size task, half of the stimuli were as [4C **4C**] and the other half were in the form of [$4M_1$ **$4M_1$**]. Each pair of the stimuli repeated twice, once with the correct answer on the left and the other on the right in two different blocks of the same task.

There were four blocks in the experiment, two of which were mathematical value tasks and the other two were font size tasks. Each type of task alternated with one another. The order of the tasks was counter-balanced. That is, half of the participants performed the mathematical value task first and the other half accomplished the font size task first. Each block was composed of 72 trials (24 congruent trials, 24 incongruent trials, and 24 neutral trials). Consequently, there were 288 trials in total.

The order of the trials within a block was randomised. The experimental programme was written with E-prime 2.0 (Psychology Software Tools, Sharpsburg, PA, USA). The phrase shown on the left was set as 42% on the x-axis while the phrase on the right was at 58% on the x-axis.

Procedure

There were twelve practice trials to ensure that participants fully understood the task. At the beginning of each block, the screen showed the task and instruction. Then, a fixation cross appeared for 1000 ms. In each trial, participants had up to 6000 ms to respond after the stimuli appeared (Figure 1). The inter-trial interval was 1000 ms. The responses and RT were recorded.

(Insert Figure 1 roughly here)

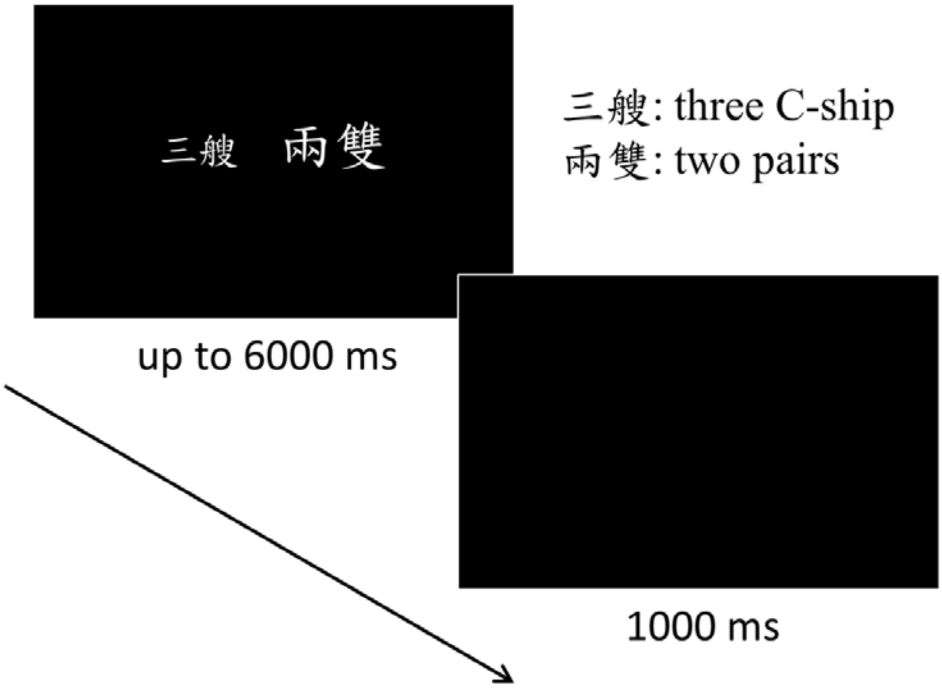

Figure 1. The experimental procedure of a trial. There were two tasks in the current experiment: the mathematical value task and the physical size task. Participants had up to 6000 ms to choose the phrase that represented a larger quantity or the one that was shown in a larger font size according to the task instructions. The inter-trial interval was 1000 ms. The stimuli shown here were an example of the congruent condition (i.e., 3C $\mathbf{2M_1}$) with close distance (distance = 1) in the mathematical value task. Note that the stimuli in this figure were not exactly the same size as used in the experiment. They were enlarged proportionately to better demonstrate the experimental conditions.

Data analysis

Among the twenty participants, one participant was excluded from the data analysis because of data loss. Mean RT were calculated from correct trials only. Furthermore, in order to combine accuracy and RT in a single measure, we also analysed a standardised performance score as an index of overall performance (25). The standardised performance score was obtained by, firstly, subtracting the Z score of RT from the Z score of accuracy, then, dividing this number by two. Higher scores (i.e., higher accuracy and shorter RT) indicate better overall performance.

The responses, RT, and standardised performance scores were analysed in a three-way (Task × Congruity × Distance) repeated measures ANOVA. SPSS 21 (IBM, Armonk, NY, USA) was used for the statistical analysis with the α value set at .05. Post-hoc analyses of the simple main effects were made by means of t-tests applying Bonferroni's correction for multiple comparisons.

Results

The mean (and standard error of the mean, SEM) of accuracy, RT, and standardised performance score are shown in Figure 2.

Accuracy

There was a significant main effect of task, such that the accuracy of the physical size task (97.4%) was significantly higher than that of the mathematical value task (95.3%), $F_{(1,18)} = 5.109$, $p < .05$ (Figure 2a). The main effect of congruity was also significant, such that the accuracy of incongruent trials was the lowest compared to congruent and neutral trials (94.8% vs. 97.3% vs. 97.1%; respectively), $F_{(2,36)} = 5.373$, $p < .01$. Moreover, there was a significant main effect of distance, such that the accuracy of close distance (94.7%) was significantly lower than that of far distance (98.1%), $F_{(1,18)} = 21.350$, $p < .001$. No significant interaction effect between task and congruity ($F_{(2,36)} = .246$, $p = .783$), or, task and distance ($F_{(1,18)} = .298$, $p = .592$) was found. However, there was a significant interaction between congruity and distance, $F_{(2,36)} = 6.555$, $p < .01$ (Figure 2b). Lastly, the three-way interaction between task, congruity, and distance was not significant, $F_{(2,36)} = 2.192$, $p = .126$.

(Insert Figure 2 roughly here)

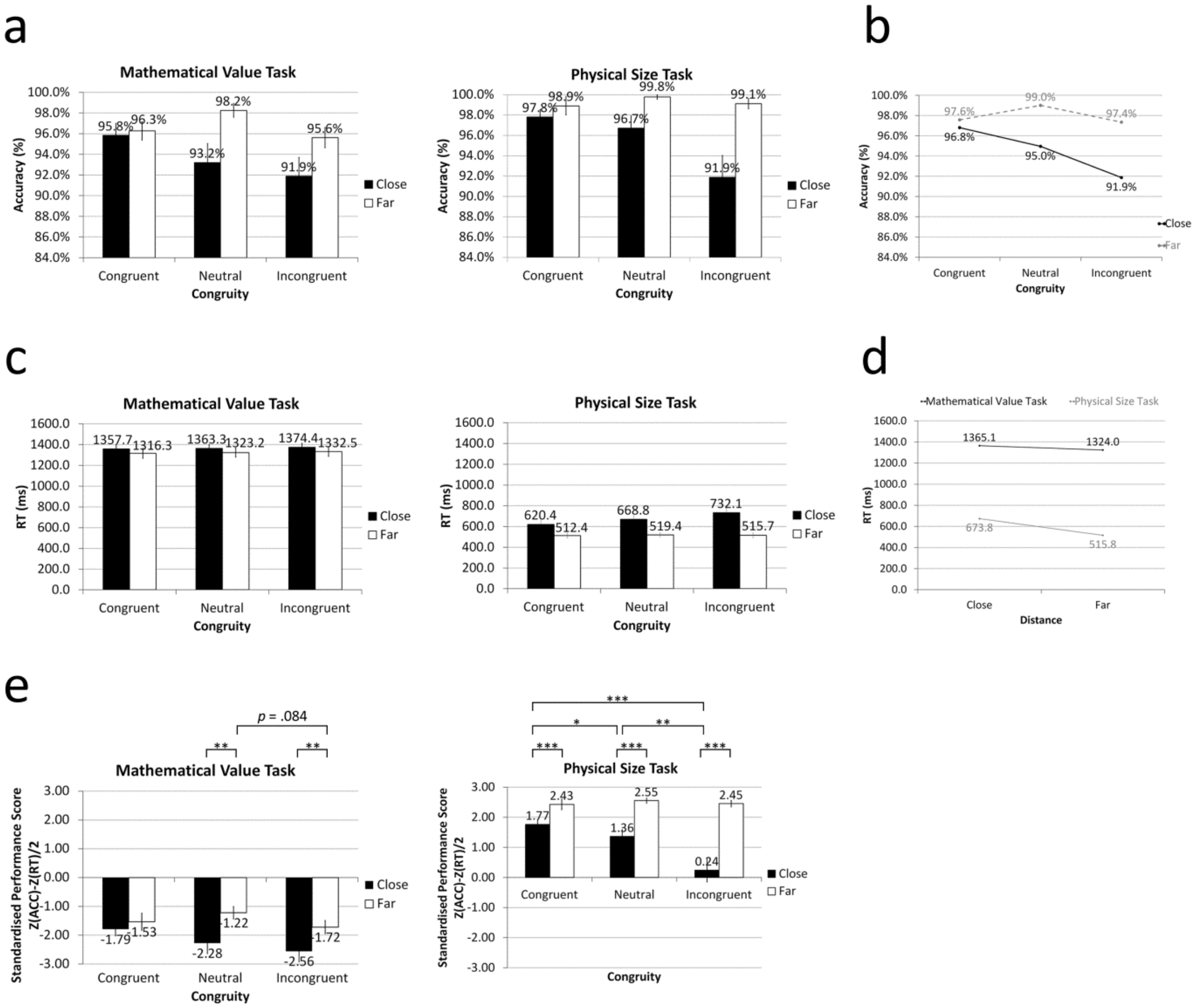

Figure 2. (a) Mean accuracy, (b) interaction of accuracy between congruity and distance, (c) mean RT, (d) interaction of RT between task and distance, and (e) mean standardised performance score. Error bars indicate standard error of the mean (SEM). Asterisk * marks $p \leq .05$, ** marks $p \leq .01$, *** marks $p \leq .001$.

Reaction times

There was a significant main effect of task, such that the RT in the mathematical value task (1344.57 ms) were significantly longer than in the physical size task (594.82 ms), $F_{(1,18)} = 262.907$, $p < .001$ (Figure 2c). Nevertheless, the main effect of congruity was not significant, $F_{(2,36)} = 2.734$, $p = .078$. The main effect of distance was significant, such that the RT of close distance (1019.46 ms) were longer than those of far distance (919.93 ms), $F_{(1,18)} = 43.713$, $p < .001$. Furthermore, the distance effect was larger in the physical size task, leading to a significant interaction between task and distance, $F_{(1,18)} = 17.149$, $p < .01$ (Figure 2d). No significant interaction effect between task and congruity ($F_{(2,36)} = .840$, $p = .440$), or , congruity and distance ($F_{(2,36)} = 2.363$, $p = .109$) was found. Lastly, there was no significant three-way interaction effect between task, congruity, and distance, $F_{(2,36)} = 2.015$, $p = .148$ (Figure 2b).

Standardised performance score

There was a significant main effect of task, such that the standardised performance score in the physical size task was significantly higher than in the mathematical value task, $F_{(1,18)} = 184.124$, $p < .001$ (Figure 2e). The lower score for incongruent compared with congruent and neutral trials (-.395 vs. .217 vs. .105; respectively) led to a significant main effect of congruity, $F_{(2,36)} = 7.480$, $p < .01$. Moreover, the main effect of distance was also significant, such that the standardised performance score for close distance (-.542) was lower than that for longer distance (.494), $F_{(1,18)} = 62.268$, $p < .001$. There was a significant three-way interaction effect between task, congruity, and distance, $F_{(2,36)} = 4.280$, $p < .05$. The distance effect was only absent for the congruent condition in the mathematical value task. Furthermore, the congruity effect was significant for close distance rather than far distance in the physical size task. Notably, in the mathematical value task, the score difference between the far distance & neutral condition and far distance & incongruent condition was marginally significant, $p = .084$.

Discussion

In the present experiment we examined the role of mathematical values of C/Ms using the number-size comparison task. In terms of accuracy, first, we observed that participants responded more accurately when comparing the physical size of the C/M phrases than the mathematical values of C/M phrases. Moreover, as predicted, we found that participants answered more accurately when making a judgment between stimuli with farther distance (i.e. either mathematical value or physical size) regardless of the tasks. Furthermore, incongruent trials led to the lowest accuracy rate than neutral and congruent trials in both tasks. This reflected that the mathematical values of C/Ms and physical size interfered with the other. Last but not least, distance and congruity showed an interaction effect. Participants were more easily affected by the information from the irrelevant dimension (size/value) when comparing the stimuli with closer value/size distance. To be more specific, when participants make a judgment between a pair with small numerical/physical distance, accuracy of congruent pairs was facilitated while that of incongruent trials was hindered. On the other hand, congruity did not have such an impact on stimuli with far value/size distance.

Not surprisingly, participants spent longer time comparing the mathematical values of C/Ms than physical size. In addition, similar to the accuracy rate, distance effect of RT was observed. Although the distance effect was more profound in the physical size task, mathematical value task also revealed the same trend that the closer the distance, the longer the RT. However, congruity did not have a significant influence on RT. Notably, the mean RT in the mathematical value task was relatively long (1344.57 ms). As literature suggested, the congruity effect occurs due to automatic processing of irrelevant information (26, 27). It was possible that the long RT in the mathematical value task provide more time to inhibit the response to irrelevant information. Though not significant, physical size task exhibited the pattern of facilitation for congruent trials (shorter RT than neutral trials) and interference for incongruent trials (longer RT than neutral trials) when comparing stimuli with close physical size. This suggests that the mathematical value of C/Ms may have some interference effect on RT of physical size. Nonetheless, it can be seen that the mean RT for far distance in the physical size task was extremely short and almost the same among the three conditions of congruity. This may indicate that comparing physical sizes with far distance was too easy to respond to before the irrelevant information (i.e., mathematical value of C/Ms) could interfere.

Since accuracy and RT did not display the same pattern, we also looked into the standardised performance score, which is an index of overall performance. The results were very similar to the findings of accuracy. Firstly, participants performed better in the physical size task compared to the mathematical task. Second, except for the congruent trials in the mathematical value task, distance effect emerged in all other conditions. This was probably because that the consistent physical size facilitated the performance for comparing C/Ms with close distance in the mathematical value task, making it as comparatively easy as comparing C/Ms with far distance and resulting in non-significant difference between them. However, marginal interference effect ($p = .084$) was observed in comparing C/Ms with far distance between the neutral and incongruent conditions. As found in RT results, congruity effect was not as apparent in the mathematical value task as in the physical size task. One possible reason may lie on the limitation that there was a fundamental difference between semantic processing and perceptual processing. Moreover, although previous studies showed that numerical value interfered with physical size (13, 23-24), their stimuli were digits instead of Chinese C/M phrases, which indeed had higher processing requirements and even longer RT. Since congruity effect was manifested when participants could not ignore the irrelevant information, longer RT in the mathematical value task may instead be beneficial to participants for having more time to inhibit the influence by the irrelevant information. This may explain why interference effect from the physical size was alleviated in the mathematical value task. On the other hand, the congruity effect was remarkable when comparing physical sizes with close distance. This demonstrated that the mathematical value of C/Ms impeded the process of comparing similar physical sizes.

Taken together, if C/Ms denote mathematical values and form a multiplicative relation with Num, we should be able to observe typical features of magnitude processing, i.e., distance effect (12, 16-20) and congruity effect (13, 23-24). Certainly, participants performed better at comparing the two distant stimuli than the proximate ones. This was consistent with the view that mental representation of adjacent numbers overlap to some degree. It is thus more difficult to distinguish them than remote numbers (15). Moreover, participants' performance was affected by the irrelevant information from the other dimension, suggesting that the mathematical values of C/Ms and physical size interfere with each other mutually. This was in line with Walsh (22), who suggested that there is a common coding system of numerical and physical dimensions. Moreover, accuracy rates showed interaction between congruity and distance, such that the congruity effect was more pronounced when participants compared stimuli with closer distance. To be more specific, when the task on hand was at a higher difficulty level, influence from the irrelevant dimension was crucial. Performance of congruent trials may be facilitated whereas that of incongruent trials could be worsened.

To summarise, these findings supported Her's (6) theory, which indicated that C and M converge as the multiplicand — with Num as the multiplier — and diverge with different mathematical values, i.e., C = 1, M ≠ 1. If C/Ms did not denote mathematical values, characteristics of number processing would not have been observed in the current study. Moreover, if the relation between Num and C/M was not multiplication, we should not have found the distance effect because the distance between the stimuli was manipulated as Her's (6) theory provided, which is **[Num X N] = [[Num** × X**] N].**

In conclusion, this study contributed to the literature by offering empirical evidence of quantity processing of C/Ms. While Cui et al. (8) reported that the neural correlates of processing numeral classifiers was similar to that of tool nouns instead of that of numbers and dot arrays using the semantic distance comparison task, Her et al. (7, 9) followed the same paradigm but showed different behavioural and neuroimaging results, which suggest that C/Ms represent quantity. Moreover, our results also showed that the mathematical value of C/M and physical size interfere with each other, suggesting that these two dimensions may share common cognitive mechanisms (22). This was consistent with the neural evidence that processing numeral classifiers, numbers, dot arrays, and number words elicited conjunct activations in the IPS (9). Last but not least, results from the current experiment not only demonstrated with a different task that C/Ms denote mathematical values (C = 1, M ≠ 1) but also verified that the relation between Num and C/M is multiplication. Because previous studies only used 1 as Num in C/M phrases (7-9), the relation between Num and C/M remained unknown. However, our experiment found the distance effect and congruity effect with a range of combinations of Num and C/Ms as stimuli, verifying that Num and C/M form a multiplicative relation (6). In sum, the linguistic system of C/M interacts with magnitude cognition.

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Author contributions

O.-S.H. and N.-S.Y. conceived the study. Y.-C.C., O.-S.H., and N.-S.Y. designed the study. Y.-C.C. developed stimuli, collected and analyzed the data. Y.-C. C., N.-S.Y., and O.-S.H., interpreted the data. Y.-C.C. and O.-S.H. wrote the paper.

Competing final interests

There is not any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence, our work.

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移地研究心得報告

計畫編號	MOST 103-2410-H-004 -136 -MY3
計畫名稱	漢語分類詞與量詞的分與合：探究其內在之認知機制與神經關連性
出國人員姓名 服務機關及職稱	陳盈君 國立政治大學語言所 專任研究助理
時間地點	2016 年 8 月 6 日- 11 月 3 日美國史丹佛大學心理系

一、心得摘要

本次前往美國史丹佛大學心理系進行移地研究，主要至 Dr. Jeanne Tsai 的 Culture and Emotion Lab 和 Dr. Brian Knutson 的 Symbiotic Project on Affective Neuroscience Lab 實習，學習執行行為與 fMRI 實驗的方法與技術，這段時間，工作內容包含翻譯實驗材料、收集在香港、台灣、中國的行為資料，分析行為實驗結果，並發展為 fMRI 實驗派典，這次的經驗也讓我學習到其他實驗室對 fMRI 實驗設計與分析的思考方式。在實驗室學習的過程中，我也完成了執行人體實驗所須完成的 Collaborative institutional training initiative (CITI Program)，並通過三階段的 MRI 安全訓練，也多次見習並協助 Dr. Yang Qu 操作 MRI 儀器。在移地研究期間，很幸運能夠每週定期參加這兩個實驗室的會議，接收到他們目前最新的研究成果。

Dr. Jeanne Tsai 所主持的 Culture and Emotion Lab 目前有多個研究計畫同時在進行，目前有一個主要的研究是透過運用 fMRI 來檢視文化對於情緒與決策的影響，他們在 Dictator game(獨裁者賽局)的 fMRI 研究中發現，受試者在分錢給表情與自己理想情緒相符的對手時，大腦中與 theory of mind 相關的腦區，如 right temporalparietal junction(顳頂交界區)的活化較低，代表受試者較容易理解對方，進而願意分較多錢給對手。目前這個研究計畫正在香港、台灣、中國等地方收集更多資料，這個計畫同時結合了心理、文化、神經科學等領域，是跨文化的神經科學研究的一大進展。

Dr. Brian Knutson 所主持的 Symbiotic Project on Affective Neuroscience Lab (SPAN lab) 主要研究重點為神經經濟學，探討各種不同情緒與決策背後的神經機制，研究議題十分廣泛，包含：使用 Diffusion tensor imaging (DTI)追蹤 anterior insula(前島)與 Nacc(伏隔核)

和 ventral lateral prefrontal cortex(腹內側前額葉皮質)之間的結構性連結來探討抑制行為；透過模型分析，發現 Nacc(伏隔核)的活化可預測股票價格；藥物成癮者在復發時的腦活化情形；比較兩種不同模型，發現 Bayesian rule-based learning model 比起傳統的 reinforcement learning model 更能預測 striatum(紋狀體)所表徵的 prediction error。我在 SPAN lab 學習到可透過使用不同的 MRI 技術來幫助解答不同的研究問題,包含結構性與功能性磁振造影，再搭配大量的模型分析與模型比較，來驗證最符合資料型態的理論。

另外，我也參與由 Dr. Russell Poldrack 教授的 fMRI 課程，學習更多 fMRI 資料的處理與分析技術，Dr. Russell Poldrack 所主持的實驗室開發了許多幫助腦造影研究資料分析的相關工具，近年他們也在推動建立磁振造影資料庫的計畫，透過分享腦造影資料、磁振造影處理與分析的程式等，以增進神經科學研究的可重複性。在課程當中，除了 MRI 影像前處理、GLM 統計導論、first level modeling、group analysis 等原理說明外，更搭配實作練習，學習在 linux 系統上使用 python、github、jupyter notebook 等工具進行資料前處理與分析，MRI 資料處理時最常遇到的困難就是受試者的頭動問題，在課堂中 Dr. Russell Poldrack 也分享他們實驗室使用 FSL 前處理的步驟，也示範了許多資料前處理時的輔助軟體，例如透過 MRIQC 評估影像品質，避免有問題的影像影響分析結果，或是使用 mango 快速檢查影像雜訊與對比等特質。

除了在實驗室中協助收集與分析資料、在課堂中學習 fMRI 分析技術外，許多的收穫更來自史丹佛大學心理系舉辦的各種大小型學術活動。暑期的 Psych-Summer program 提供大學部學生發表壁報論文，報告研究成果，研究主題都相當新穎有趣，例如有一個社會語言學的研究，語料來自餐廳菜單中的描述，他們發現餐廳在形容健康的菜色與不健康的菜色時所使用的詞彙有很大的差別，而且不健康菜色所使用的字眼較吸引人，例如：多汁的、垂涎的等，這研究也引發後續討論—是否可透過改變菜單中的詞彙描述，讓健康的菜色變得對人們更有吸引力。

十月十四日適逢 Stanford Center for Cognitive and Neurobiological Imaging (CNI)五週年，CNI 中心舉辦了主題演講，也邀請了中心成員透過壁報發表分享近期的研究成果。其中，Dr. Nikos Logothetis 分享他們利用 neural-event-triggered fMRI(NET-fMRI)的技術觀

察 thalamus(視丘)與 hippocampus(海馬迴)的神經網路，並探討這樣的神經連結性如何鞏固不同類型的記憶；Dr. David Eagleman 則發表他多年來一系列的研究議題，三大主題包含了時間知覺、聯覺、感官替代，其中最精采的便是感官替代這個主題，Dr. David Eagleman 的實驗室開發了一種非侵入性的震動背心給有聽力障礙的人穿，這件背心上面有許多的震動元件，當背心上的麥克風接收到聲音，這件背心就會震動，他們發現，經過練習，聽障患者可以學會辨別不同的震動模式，並知道造成此震動的字詞是什麼。其中一篇壁報論文是 Dr. Brian Wandell 實驗室所做的研究，Dr. Brian Wandell 長年透過磁振造影(MRI)技術來研究視覺皮質區，他們的研究方法結合了功能性磁振造影、結構性磁振造影與視覺處理的模型分析，近年將視覺的基礎研究延伸至閱讀上，他們測量大腦中的 ventral occipital temporal reading circuitry 的 field of view(FOV)，發現這個區域會選擇性的對文字做出反應，他們也推論這個區域的個人差異會影響到閱讀能力。

史丹佛大學心理系每個月會舉辦一到兩場學術討論會，有時是學者演講，有時則是由系上博士班學生以 lightning talk 的方式發表實驗結果，研究主題包含了各種領域：發展心理學、社會語言學、認知神經科學等。此外，心理系的各個次領域每週都會有研討會，例如 social lab、culture-co lab、affective seminar、memory decision lunch、Friday seminar 等，整體來說，可以發現不論在哪個次領域，所有的研究題目皆非常新穎並且具有應用性。

總結來說，這次移地研究獲益匪淺，透過實際參與計畫執行、修習 MRI 課程、參與演講與研討會，吸收各領域最新的知識，了解目前的研究發展趨勢，激發更多研究構想，透過和史丹佛大學的教授與學生每天一起工作，密切學術交流，收穫豐盛。

二、 相關聯結

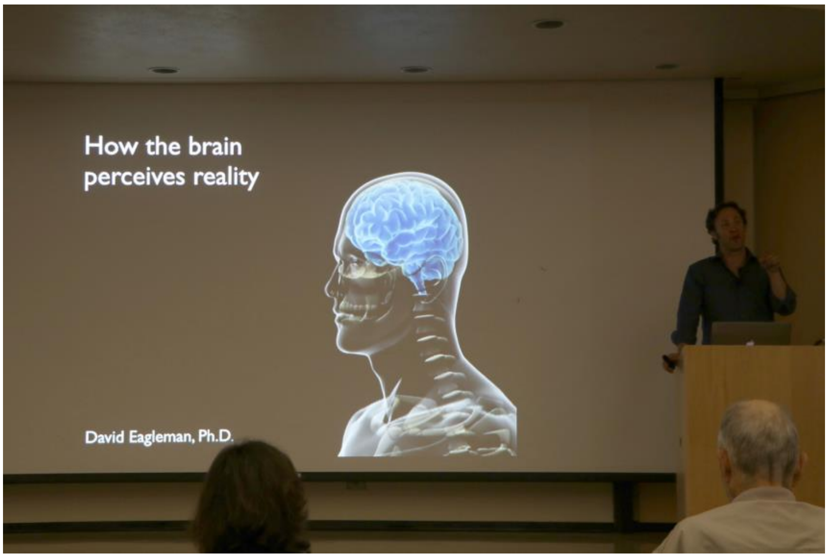
Culture and Emotion Lab https://culture-emotion-lab.stanford.edu/
SPAN Lab http://stanford.edu/group/spanlab/
Poldrack Lab https://poldracklab.stanford.edu/
Stanford Center for Cognitive and Neurobiological Imaging http://cni.stanford.edu/

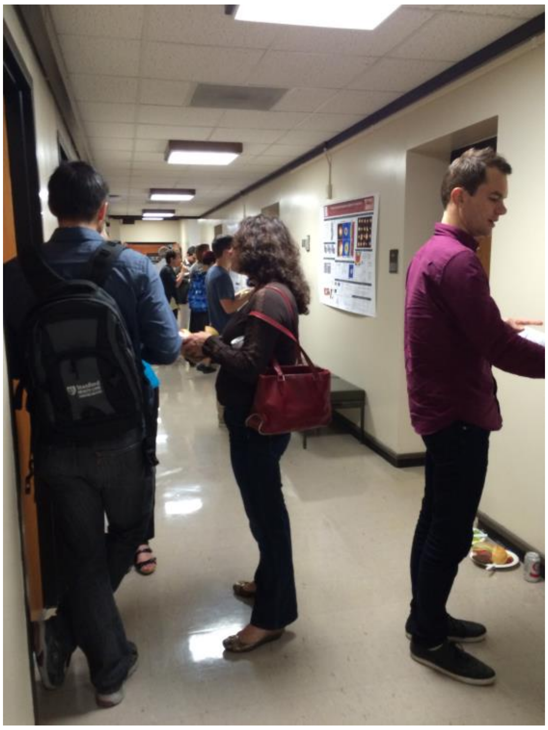
三、　　相關照片

Culture and Emotion Lab

Psych-Summer Program Poster Session

Stanford Center for Cognitive and Neurobiological Imaging (CNI) 5^{th} Year Celebration





COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Ying-Chun Chen (ID: 5707813)
- **Email:** phoebe.yc.chen@gmail.com
- **Institution Affiliation:** Stanford University (ID: 389)
- **Institution Unit:** Psychology
- **Phone:** 6507240534

- **Curriculum Group:** Human Subjects Research Protections
- **Course Learner Group:** Group 2: IRB Required for Nonmedical Research Investigators and Staff
- **Stage:** Stage 1 - Basic Course
- **Description:** (Choose this group to satisfy CITI training requirements for investigators and staff involved in human subject research from the Graduate School of Business, School of Earth Sciences, School of Education, School of Engineering, School of Humanities and Sciences, and the Law School)

- **Report ID:** 20491316
- **Completion Date:** 15-Aug-2016
- **Expiration Date:** 15-Aug-2019
- **Minimum Passing:** 80
- **Reported Score*:** 92

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
History and Ethical Principles - SBE (ID: 490)	15-Aug-2016	4/5 (80%)
Defining Research with Human Subjects - SBE (ID: 491)	15-Aug-2016	4/5 (80%)
The Federal Regulations - SBE (ID: 502)	15-Aug-2016	5/5 (100%)
Assessing Risk - SBE (ID: 503)	15-Aug-2016	5/5 (100%)
Informed Consent - SBE (ID: 504)	15-Aug-2016	5/5 (100%)
Stanford University Module (ID: 750)	15-Aug-2016	No Quiz

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

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COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Ying-Chun Chen (ID: 5707813)
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- **Institution Affiliation:** Stanford University (ID: 389)
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- **Stage:** Stage 1 - Basic Course
- **Description:** (Choose this group to satisfy CITI training requirements for investigators and staff involved in human subject research from the Graduate School of Business, School of Earth Sciences, School of Education, School of Engineering, School of Humanities and Sciences, and the Law School)

- **Report ID:** 20491316
- **Report Date:** 15-Aug-2016
- **Current Score**:** 100

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
History and Ethical Principles - SBE (ID: 490)	15-Aug-2016	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	15-Aug-2016	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	15-Aug-2016	5/5 (100%)
Assessing Risk - SBE (ID: 503)	15-Aug-2016	5/5 (100%)
Informed Consent - SBE (ID: 504)	15-Aug-2016	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	15-Aug-2016	5/5 (100%)
International Research - SBE (ID: 509)	15-Aug-2016	5/5 (100%)
Stanford University Module (ID: 750)	15-Aug-2016	No Quiz

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Assignments

Assignments

Take an Assignment

The assignments listed below are currently available for you to take. To begin, click on the assignment title.

Title	Time Limit	Due Date/Time
Level 1 Test	**n/a**	n/a
Level 2 Test	**n/a**	n/a
Level 3 Test	**n/a**	n/a

Submitted Assignments

You have completed the assignments listed below. Unless Feedback Available displays "n/a" (not applicable), feedback will be available at the time shown. If feedback is available for particular submissions, it will be seen under "View All Submissions/Scores".

View All Submissions/Scores | View Only Recorded Scores

Title	Statistics	Recorded Score	Feedback Available	Individual S
Level 1 Test	**n/a**	**10** (Last)	**Immediate**	
			Feedback	10
Level 2 Test	**n/a**	**10** (Last)	**Immediate**	
			Feedback	10
			Feedback	9
Level 3	**n/a**	**10** (Last)	**Immediate**	

出席國際學術會議心得報告

計畫編號	MOST 103-2410-H-004 -136 -MY3
計畫名稱	漢語分類詞與量詞的分與合：探究其內在之認知機制與神經關連性
出國人員姓名 服務機關及職稱	顏乃欣 國立政治大學心理系教授
會議時間地點	2017 May 25-28, Boston, U.S.A.
會議名稱	The 29th Annual Convention of Association for Psychological Science
發表論文題目	1. Quantity processing of Chinese classifiers and measure words 2. Examining affect labeling under the presentation of the Western and Eastern facial expression in Eastern people

一、與會心得摘要

心理科學學會(Association for Psychological Science, APS)年會為心理學領域最重要會議之一。APS 主要聚焦在以實證研究方法，探討心理科學(psychological science)當今重要之各項議題。本次 29 屆會議於 2017 年 5 月 25-28 日在美國波士頓舉行，邀請的主題講者(keynote speakers) Lila R. Gleitman 為美國賓夕法尼亞大學(University of Pennsylvania)心理學系榮譽教授，會議中還安排多場 APS James McKeen Cattell Fellow Awards 以及 APS William James Fellow Awards 演講，著名的會長研討會(Presidential Symposia)，並提供研究技術工作坊等，讓參與者得以一窺國際研究發展之最新趨勢，並促進與國際傑出學者之交流。

主題講者 Lila R. Gleitman 為語言學背景，但對於孩童在不同情境下(如失明的孩童與正常孩童)如何學習到母語的內在心理機制有深入的探討，包括心理詞彙(mental lexicon)的習得，語言與思考的關係等。Lila R. Gleitman 知識廣博、演講功力深厚，侃侃而談 2 小時，由其學術生涯的演進逐一道出其理論發展，獲得滿場喝采。APS William James Fellow Awards 有多位著名講者，包括 Robert J. Stern berg 與 Danial L. Schacter。Robert J. Sternberg 暢談 IQ 雖可預測學業成功，但卻無法有效預測科學論證(scientific reasoning)、創造力(creativity)、常識(common sense)、智慧(wisdom)的表現。Danial L. Schacter 則鉅細靡遺的說明近年來有關情節記憶(episodic memory)、對未來的想像(future imagining)之神

經生理機制研究的情形，闡述錯誤記憶與 temporal pole 間的關係。二位大師的風采令人著迷。另外一場 APS William James Fellow Award Address，則邀請了做 IAT (implicit association test)的著名學者 Anthony G. Greenwald，以及有進行相關內隱研究的 Elizabeth A. Phelps 與 Yarrow C. Dunham 與會，討論內隱歷程在認知、社會心理及發展心理學的相關研究。今年會長研討會(Presidential Symposia)的主題為討論我們的身體與環境的互動如何影響我們對環境的知覺，請了四位講者談此議題，其中 Jessica K. Witt 的研究非常有趣，例如：高爾夫選手表現得好的(打進洞)會覺得洞口較大，顯示出人們知覺的彈性。

除了上述重要演講外，APS 同時段通常有十場以上的演講或小型研討會舉行，選擇聆聽場次常覺得有遺珠之憾。我聽了幾個不錯的小型研討會，包括對 Neuroimaging 研究在方法學上挑戰的因應，例如：對 false positive 的統計處理，如何有效重複驗證 Neuroimaging 研究發現，fMRI 有關結果類化(generalization)的問題。另一場很不錯的研討會則討論風險態度之神經機制，風險與時間延宕的關係，以及不確定性與情緒焦慮的關係，頗有收穫。期間，我還參加了一場決策計算模型的工作坊，了解進行決策模型計算的一些方法與訣竅。

我在這場會議中有二篇有關中文語言處理及情緒調節機制為研究主題的海報發表，一篇為本計畫和政大語言所何萬順教授合作探討的中文分類詞與量詞的數學處理機制，另一篇則檢視台灣受試者觀看西方情緒人臉與東方情緒人臉所展現的情感標籤效應，得到現場聽眾的良好回應。其中情緒調節之議題在本次會議亦有多個小型研討會進行討論，顯示此議題為目前心理學研究的重要議題。

整體而言，本次會議的收穫豐盛，除了和許多研究者分享目前最新的研究結果，更由互動中獲得許多有用的回饋。可以了解心理學研究的最新發展，並能激發更多研究構想與合作機會。

二、研究成果

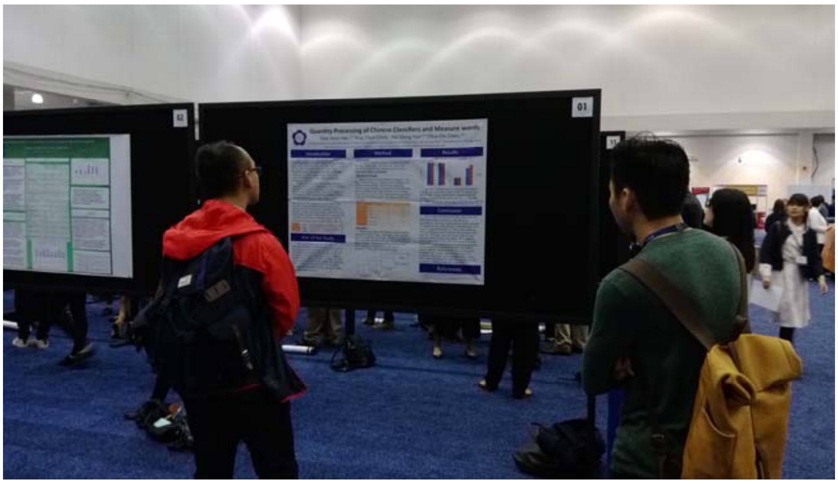
Her, O.-S., Chen, Y. C., Yen, N. S., & Chen, C. C.* (2017, May). *Quantity processing of Chinese classifiers and measure words*. Poster presented at the 29th Annual Convention of Association for Psychological Science, Boston, MA, U.S.A.

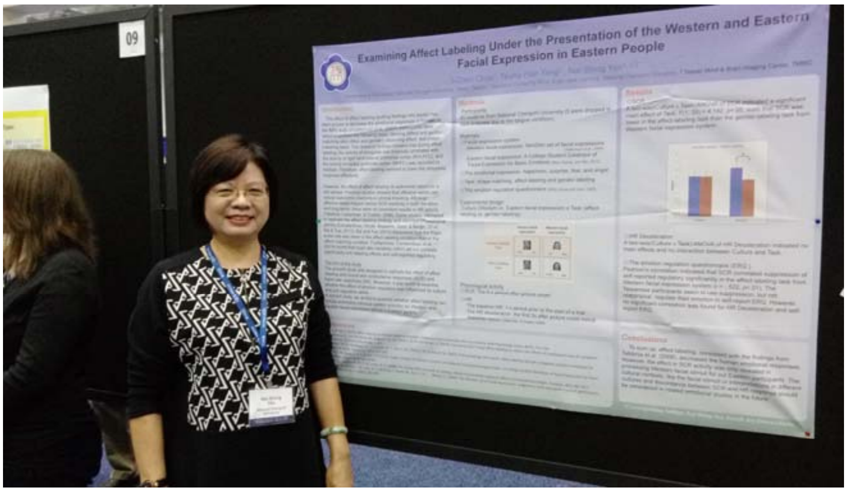
Chou, I. C., Yang, T. H., & Yen, N. S. * (2017, May). *Examining affect labeling under the* *presentation of the Western and Eastern facial expression in Eastern people*. Poster presented at the 29th Annual Convention of Association for Psychological Science, Boston, MA, U.S.A.

三、會議網站

https://www.psychologicalscience.org/conventions

四、壁報照片





103年度專題研究計畫成果彙整表

計畫主持人：何萬順	計畫編號：103-2410-H-004-136-MY3
計畫名稱：漢語分類詞與量詞的分與合：探究其內在之認知機制與神經關連性	

成果項目					量化	單位	質化（說明：各成果項目請附佐證資料或細項說明，如期刊名稱、年份、卷期、起訖頁數、證號...等）
國內	學術性論文	期刊論文			0	篇	
		研討會論文			1		Chen, Ying-Chun, One-Soon Her, Denise Hsien Wu, and Nai-Shing Yen. 2016. Semantic Attributes and mathematical values in the processing of Chinese classifiers and measure words. Presented at the 2016 Annual Meeting of Taiwan Society of Cognitive Neuroscience, January 23, 2016 National Chengchi University, Taipei, Taiwan.
		專書			0	本	
		專書論文			0	章	
		技術報告			0	篇	
		其他			0	篇	
	智慧財產權及成果	專利權	發明專利	申請中	0	件	
				已獲得	0		
			新型/設計專利		0		
		商標權			0		
		營業秘密			0		
		積體電路電路布局權			0		
		著作權			0		
		品種權			0		
		其他			0		
	技術移轉	件數			0	件	
		收入			0	千元	
國外	學術性論文	期刊論文			2	篇	Her, One-Soon, Ying-Chun Chen, Nai-Shing Yen*. 2018. Neural correlates of quantity processing of Chinese numeral classifiers. Brain and Language 176:11-18. (SSCI) . Her, One-Soon, Ying-Chun Chen, Nai-Shing Yen*. 2017. Semantic attributes and mathematical values in the processing of Chinese numeral classifiers and measure words. PLOS ONE 12(9): e0185047.

					https://doi.org/10.1371/journal.pone.0185047 (SCI)
		研討會論文	3		Chen, Y. C., Her, O.-S., Wu, D. H., Yen, N. S. (2016, March). Semantic attributes and mathematical values in the processing of Chinese classifiers and measure words. Presented at the 2016 Annual Meeting of the Cognitive Neuroscience Society, April 2-5, 2016, New York Hilton Midtown, New York. Chen, Y. C., Her, O.-S., Wu, D. H., Yen, N. S. (2016, June). The Neural Correlates of Mathematical Processing of Chinese Numeral Classifiers and Measure Words. Poster session presented at the 22 rd Annual Meeting of the Organization of Human Brain Mapping, Geneva, Switzerland. Her, O.-S., Chen, Y. C., Yen, N. S., Chen, C. C. (2017, May). Quantity processing of Chinese classifiers and measure words. Poster session presented at the meeting of 29th Annual Convention of Association for Psychological Science, Boston, US.
		專書	0	本	
		專書論文	0	章	
		技術報告	0	篇	
		其他	0	篇	
	智慧財產權及成果	專利權 發明專利 申請中	0	件	
		專利權 發明專利 已獲得	0	件	
		專利權 新型/設計專利	0	件	
		商標權	0	件	
		營業秘密	0	件	
		積體電路電路布局權	0	件	
		著作權	0	件	
		品種權	0	件	
		其他	0	件	
	技術移轉	件數	0	件	
		收入	0	千元	

<table>
<tr><td rowspan="10">參與計畫人力</td><td rowspan="5">本國籍</td><td>大專生</td><td>0</td><td rowspan="10">人次</td><td></td></tr>
<tr><td>碩士生</td><td>0</td><td></td></tr>
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<tr><td colspan="4">其他成果
（無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。）</td><td colspan="2"></td></tr>
</table>

科技部補助專題研究計畫成果自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現（簡要敘述成果是否具有政策應用參考價值及具影響公共利益之重大發現）或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標
□未達成目標（請說明，以100字為限）
　　□實驗失敗
　　□因故實驗中斷
　　□其他原因
說明：

2. 研究成果在學術期刊發表或申請專利等情形（請於其他欄註明專利及技轉之證號、合約、申請及洽談等詳細資訊）

論文：■已發表　□未發表之文稿　□撰寫中　□無
專利：□已獲得　□申請中　■無
技轉：□已技轉　□洽談中　■無
其他：（以200字為限）
Her, One-Soon, Ying-Chun Chen, Nai-Shing Yen. 2018. Brain and Language 176:11-18.
Her, One-Soon, Ying-Chun Chen, Nai-Shing Yen. 2017. PLOS ONE 12(9): e0185047.

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性，以500字為限）

綜合本研究的兩個行為與一個腦造影實驗，結果發現，C/M確實含有數量的概念，且扮演被乘數的角色；在神經機制方面，C/M會誘發在腦中與數量處理相關的腦區較高的活化，支持Her（2012a, 2012b）的理論。另外，腦造影研究結果也反映，不同的符號所代表的數量概念都會誘發大腦頂內溝（IPS）較高的活化，這些結果顯示分類詞語言與數量概念之間有緊密的關聯，未來可望進一步延伸應用至教育、臨床等方面，例如有數學障礙的學童、頂葉損傷的病人，若是他們處理數量概念有困難，也可能影響他們在使用分類詞時的表現。

4. 主要發現

本研究具有政策應用參考價值：■否　□是，建議提供機關
（勾選「是」者，請列舉建議可提供施政參考之業務主管機關）
本研究具影響公共利益之重大發現：□否　□是
說明：（以150字為限）