Title

Transparent Vietnamese number-naming system facilitates first graders transcoding—a cross-linguistic study with French.

Cognitive Development,

Abstract

The Vietnamese number-naming system more transparently expresses base-10 than the French one does. Our study aimed to examine the language (base-10) effect on the transcoding performance and error nature in 68 French-speaking (FS) children and 173 Vietnamese-speaking (VNS) children in the first grade. They were presented with two transcoding tasks: verbal- and analog-Arabic. The results showed that the VNS children performed better than the FS children on both of the transcoding tasks. The FS children committed more lexical errors than the VNS children did, while the syntactic error rates were not different. We conclude that the transparency of the base-10 expressions or the reduced number lexicon led to a better transcoding performance in the VNS children, and the nature of the transcoding error reflects differences in the number-naming system. The differences in transcoding performance and errors are discussed based on the integration of the transcoding theoretical frameworks.

Keywords*:* transcoding; cross-linguistic; base-10; number-naming system; lexical errors; syntactic errors.

Introduction

Several Asian languages (Chinese, Japanese, Korean, and Vietnamese) have a verbal number system which is much more transparent with respect to decimal or base-10 structure than most Western number naming systems (Berch et al., 2018). For instance, they do not have words for eleven or forty but say "ten-one" and "four-ten", respectively. Several studies have shown that, probably due to the transparency of their base-10 number system, Asian children outperform Western children on a variety of numerical abilities. This is the case for counting (Lê & Noël, 2020; Lonneman et al., 2019; Miller et al., 1995; Miller & Stigler, 1987; Rodic et al., 2015; Xu & LeFevre, 2018), arithmetic fact retrieval (Geary et al., 1993; Rodic et al., 2015), number line (Göbel et al., 2011, for a review; Helmreich et al., 2011), number identification and non-symbolic arithmetic (Xu & LeFevre, 2018), collection comparison (Rodic et al., 2015; Lonneman et al., 2019), number comparison (Lonneman et al., 2016; Rodic et al., 2015), base-10 canonical representation of a number (e.g., two ten-blocks and three unit-blocks for the number 23) (Miura et al., 1988; Miura & Okamoto, 1989; Miura et al., 1993; Miura et al., 1994; Saxton & Towse, 1998) and place-value understanding (e.g., the meaning of the individual digit in a multidigit number) (Bahnmueller et al., 2018, for a review; Miura et al., 1994).

Number transcoding is a fundamental process in mathematical learning. Typically, children need the first three years of formal schooling to master transcoding skills between the spoken and Arabic number systems (Noël & Turconi, 1999). Many studies have shown that the number-naming system's characteristics affect transcoding (Dowker & Nuerk, 2016, for a review; Moeller et al., 2015; Nguyen & Grégoire, 2014; Seron & Fayol, 1994).

Indeed, although all number-naming systems are characterized by a lexicon and a syntax (Fayol & Seron, 2015), these vary significantly from one language to another (Hurford, 1987). The lexicon corresponds to the lexical primitives or the different words used to refer to numerical quantities. For instance, in English, words represent units (one, two, three, etc.), teens (eleven, twelve, thirteen, etc.), decades (ten, twenty, thirty, etc.), multipliers (hundred, thousand, million, etc.) and zero. The syntax corresponds to the rules used to combine the lexical primitives and reflects the relationship between them as additive (twenty-four, thirty-six, etc.) or multiplicative compositions (two hundred, three thousand, etc.).

Language Effect on Transcoding Tasks

Different study designs have been carried out to measure various specific language effects on transcoding abilities (Table 1). In this section, we focus on studies that examine the effect of language on children's transcoding, excluding the studies on adults as in Ganayim et al. (2020) or Poncin et al. (2020). In addition, studies that examined the effect of base-10 language transparency will be explained in more detail as they are more related to the topic of this study.

Studies on the effect of language's base-10 transparency on transcoding tasks are scarce. To the best of our knowledge, two studies investigated this effect on transcoding tasks: one on first-grade children (Moeller et al., 2015) and the other on older children from grades 3 to 6 (Nguyen & Grégoire, 2014). The first study (Moeller et al., 2015) investigated a small sample of

20 Japanese and 20 German first-grade children and mainly focused on the inversion effect and the German children's transcoding errors. For this reason, this study will be detailed below in the section regarding the inversion effect.

Table 1

Cross-linguistic Studies on Transcoding Tasks: type of contrasts and effects

Language contrast	Within-language design	Between-language design	Language effect
Transparent vs. Nontransparent	–	Vietnamese vs. French (Nguyen & Grégoire, 2014)	Decimal (base-10) effect
Transparent vs. Inverted	–	Japanese vs. German (Moeller et al., 2015)	Inversion & base-10 effect
Noninverted and Nontransparent	French** (Seron & Fayol, 1994)	English vs. French (Van Rinsveld & Schiltz, 2016)	Vigesimal (base-20) effect
Noninverted vs. Inverted	Czech (Pixner et al., 2011)	French; English vs. German; Dutch (Clayton et al., 2020; Imbo et al., 2014; Krinzinger et al., 2011; Poncin et al., 2020; Zuber et al., 2009)	Inversion effect

Arabic vs. Hebrew*

(Ganayim et al., 2020)

Note. European languages: English, French, German, Dutch, Czech

East Asian languages : Vietnamese, Japanese

* Middle Eastern Languages: Arabic and Hebrew. Arabic has the inversion property but Hebrew does not.

** French from France and Wallonia (Belgium)

The second study (Nguyen & Grégoire, 2014) showed that grade-4 Vietnamese students (N = 690) performed better than their Belgian peers when transcoding written verbal to Arabic numbers and reached the same level as grade-6 French-speaking Belgian students (N = 127). However, Nguyen & Grégoire (2014) focused mainly on the transcoding effects of syntactic zero. Indeed, in Vietnamese, the syntactic zero is represented explicitly in spoken numbers; for instance, "25014" is spoken as, "hai mươi lăm nghìn không trăm mười bốn" (literally, "two ten five thousand zero hundred ten four"), while in French, the syntactic zero is silent, "25014" is "vingt-cinq milles quatorze" (literally, "twenty-five thousand fourteen"). They found that French-speaking children mainly erased the zero (i.e., omission error) that was not present in the verbal form of the number (e.g., the typical response for "twenty-five thousand fourteen" [25014] is 2514).

Other studies examined the impact of lexical and syntactic variation on transcoding performance. For instance, Seron and Fayol (1994) compared the French number-naming system in Belgium and France. In Belgium, decade numbers such as 70 and 90 are spoken "seventy" ("septante") and "ninety" ("nonante"), while in France, 70 is "sixty-ten" ("soixante-dix") and 90 is "four twenty-ten" ("quatre-vingt-dix"). In dictating these types of numbers, 7-year-old French children produced more errors than the Belgian children did. The French children produced particular syntactic errors corresponding to a full or partial transcript of verbal lexical primitives

(e.g., "soixante-dix huit", literally "sixty-ten eight" written as 6108 or "quatre-vingt-dix-sept", literally, "four-twenty-ten seven" written as 4217, 42017, or 8017). Similar results were found when comparing 10-year-old French- and English-speaking children (Van Rinsveld & Schiltz, 2016).

Moreover, much of the previous research has investigated the language effect on transcoding, studied the lexical influences (see Dowker & Nuerk, 2016, for a review). The majority of these have focused on the inversion effect, i.e., the impact of the inversion of the unit-decade order in a certain number-naming system (Klein et al., 2013, see also Table 1). Indeed, in some languages, such as Dutch and German, the unit word is expressed before the decade word (e.g., "twenty-five" is expressed as "five and twenty"). Studies have shown that children using these inverted number-naming systems had lower transcoding performance than children using a noninverted system (such as French or English; see Imbo, Vanden Bulcke, De Brauwer, & Fias, 2014; Krinzinger et al., 2011; Zuber, Pixner, Moeller, & Nuerk, 2009) and committed more inversion errors ("46" → 64) (Clayton et al., 2020; Imbo et al., 2011; Moeller et al., 2015).

The last study (Moeller et al., 2015) compared the transcoding errors of German and Japanese speaking children. The German and Japanese number systems differ in two dimensions: first, German is inverted, Japanese is not and second, Japanese is much more transparent to the base-10 than German (Table 1). In this study, children were asked to write Arabic numbers of 1 to 3 digits under dictation. The result showed that inversion errors (e.g., “twenty-five” = “five and twenty”→52) were the largest category of errors in German-speaking children, but were almost absent in Japanese-speaking children. In contrast, almost all errors produced by Japanese children were related to additive composition (e.g.,“three hundred twenty”→ 30020, when twenty is appended in the composition rather than added). Another study (Pixner et al., 2011) tested the inversion effect in children speaking two contrasting number-naming systems, inverted and

noninverted, in the same country (Czech). In particular, Czech children produced fewer errors in transcoding tasks from noninverted than from inverted number words (Pixner et al., 2011).

Transcoding Models

Several transcoding models have been reported. They can be divided into two main categories: semantic (McCloskey, Caramazza, & Basili, 1985; Power & Dal Martello, 1990, 1997) and asemantic models (Barrouillet, Camos, Perrucher, & Seron, 2004; Deloche & Seron, 1987).

According to the semantic models (McCloskey et al., 1985; Power & Dal Martello, 1990, 1997), the semantic representation of the number (i.e., its magnitude representation) must be activated to transcode a number. In McCloskey et al.'s (1985) model, the semantic representation is supposed to reflect a base-10 structure (e.g., 345 would be represented as $[3]10^2$ $[4]10^1$ $[5]10^0$). The production mechanisms convert this semantic representation into the target output code. The semantic base-10 representation logically implies that the verbal stimulus's peculiarities may influence the comprehension stage in the number-dictation task but would not influence the Arabic production mechanisms (Lochy, Pillon, Zesiger, & Seron, 2002).

Power and Dal Martello's (1990, 1997) semantic-verbal model also distinguishes between comprehension, production, and semantic processes. However, in this model, the semantic representation interprets the verbal number presented through additive (sum) and multiplicative (product) relationships. A concatenation operation (noted by &) is then applied for the product relationship; for example, “two hundred” yields 2 x 100 = <2> & 00 = 200, and an overwriting operation (noted by #) is used for the sum relationship; for example, “twenty-two” yields 20 + 2 = <20> # <2> = 22. According to the authors, sum relationships lead to errors more frequently than product relationships, as acquiring the overwriting operation is more difficult than acquiring the concatenation operation.

In contrast, asemantic models (Barrouillet et al., 2004; Deloche & Seron, 1987) assume that access to the numerical magnitude is not required for transcoding tasks, as the conversion of the numerical input into the output form is an algorithm-based procedure (Moura et al., 2013; Verguts & Fias, 2006). In the latest model, ADAPT (i.e., A Developmental, Asemantic, and Procedural model) from Barrouillet et al. (2004), the verbal input is stored as a phonological sequence in the short-term memory. Parsing mechanisms subdivide this sequence into smaller units that are processed by a production system. The production system has various functions: retrieving existing (learned) Arabic forms from long-term memory (LTM), managing the frame (i.e., the number of slots for the digit chain), and filling all the slots with lexical primitives (Clayton et al., 2020).

Currently, these models have been used to account for transcoding errors in children or brain-damaged patients. However, linguistic differences are not explicitly accounted for in these models.

Present Study

Purpose and questions

The present study aims to reexamine the influence of the base-10 transparency of the number-naming system on young children's transcoding performance and error nature. For that purpose, we directly compare the transcoding abilities of first graders speaking either French or Vietnamese. Our two main questions are as follows: does the base-10 transparency of the number-naming system impact the development of the transcoding ability in first-grade children? Qualitatively, how do the transcoding errors differ between the two languages according to verbal numbers' lexical and syntactic features?

Vietnamese and French contrast in their degrees of base-10 transparency, their lexicon, and their syntactic structure (see Appendix A). Vietnamese has a very limited numerical lexicon, with only the word zero, unit words (from one to nine), and words expressing ten powers. Similar number words exist in French, but French also has specific words for the teens (from eleven to sixteen) and decades (from ten to ninety). Thus, while Vietnamese has approximately 16 lexical primitives constituting their number lexicon, French has approximately the double. In Vietnamese, teens are expressed using an additive relation (e.g., "eleven" would correspond to "ten one", meaning ten plus one), and decades, using a multiplicative relation (e.g., "twenty" corresponds to "two-ten," meaning two times ten).

Based on the different theoretical models of transcoding, we proposed different predictions (Table 2).

Table 2

Resume of predictions according to the transcoding models

Variables	Main basics	Models	Predictions
Performance (success rates)			
Verbal-Arabic transcoding	Activation of a base-10 semantic representation	McCloskey et al.	VNS > FS
Analog-Arabic transcoding			VNS = FS
Transcoding errors (errors rates)			
Syntactic errors	Additive & multiplicative relations	Power & Dal Martello	VNS > FS
	Algorithmic transcoding failure	ADAPT	
Lexical errors	Larger number of primitives	McCloskey et al.	VNS < FS
	Retrieving the digital forms from LTM	ADAPT	VNS > FS

Note. = mean no difference; VNS, Vietnamese-speaking Children; FS, French-speaking children.

Predictions based on McCloskey's model

McCloskey's model (McCloskey et al., 1985) supposes the necessary activation of a base-10 semantic representation of the number for the transcoding process. Therefore, we expect the Vietnamese-speaking children to perform better than the French-speaking children on the verbal-Arabic-transcoding task, as the base-10 transparency of their number-naming system would facilitate the activation of the base-10 semantic representation of the numbers to transcode. However, if the input were similar between the two groups, such as an analog representation (i.e., pictures of sticks), no difference would be expected in producing the corresponding Arabic numbers.

Predictions based on Power and Dal Martello's model

The prediction is different when made from the model of Power and Dal Martello (1990). In this framework, Vietnamese verbal numbers involve more additive and multiplicative relations than French verbal numbers do. Indeed, for numbers such as teens (e.g., twelve) or decades (e.g., thirty), French requires no syntactical relation processing, while Vietnamese requires the processing of additive and multiplicative relations, respectively. Similarly, for numbers such as 23, French uses only an additive relation, while Vietnamese requires both a multiplicative and an additive relation. Accordingly, based on the Power and Dal Martello model, we expect to observe more syntactic errors in the Vietnamese- than in the French-speaking sample.

Predictions based on ADAPT model

Similarly, according to the ADAPT model (Barrouillet et al., 2004, using the $ADAPT^{BASIC}$ model), Vietnamese-speaking children need to process more transcoding rules than French-speaking children do. In Vietnamese, three rules are required for transcoding the teen (Pa, Pc, and Pa'), decade (Pa, Pc, and Pe'), and decade-unit structures (Pa, Pc, and Pa'). In contrast, in

French, only one rule is used for transcoding the teen structure (Pd), and two rules are used for the decade (Pb and Pe') and decade-unit structures (Pb and Pa') (see Appendix B). According to this model, algorithmic transcoding failures lead to syntactic errors; Vietnamese-speaking children would be expected to produce more syntactic errors than French-speaking children, as the former must process more transcoding rules.

Another interesting difference between the two languages is the extent of their numerical (primitive) lexicon. According to Deloche and Seron (1982a, 1982b), verbal numbers (in most Western languages) are organized into ordered lexical classes: units, teens, decades, and multipliers. For instance, the word “thirteen” is the third word in the teens class, while “forty” is the fourth word of the decades class. This conception has been integrated into McCloskey's model. For instance, McCloskey, Sokol, and Goodman (1986) described a patient who mainly produced position errors in transcoding tasks (i.e., selecting the correct lexical class but not the correct position and confusing, for instance, fifteen and thirteen). As a larger number of primitives from different classes must be processed in French while only unit words are considered in Vietnamese, McCloskey's model would also predict more lexical errors made by French- than Vietnamese-speaking children. These errors could come from difficulty in processing the class information (i.e., not knowing if the word is a unit, teen, or decade number) or in processing the position information (e.g., "thirteen", the third word in the teen class). Accordingly, we would expect more lexical errors in French-speaking children that could correspond to class (1**3** → **3**0) or position errors. In the latter case, the lexical errors would be related to unit positions (1**1** → 1**3**) when processing teen words and to the decade position (**2**4 → **1**4) when processing decade words.

The ADAPT model also considers that number words are organized into ordered classes but assumes that lexical errors are due to storage difficulty, which depends on the number of

syllables in the sequence or difficulties in retrieving the digital forms from LTM (Barrouillet et al., 2004). The items selected in this study do not differ in terms of the number of syllables (see Appendix A). However, the number of forms that must be retrieved from LTM is higher in Vietnamese than it is in French for the teens, decade, and decade-unit structures. Indeed, for numbers such as 12, 30, and 34, two ("ten-two"), two ("three-ten"), and three ("three-ten four") words, respectively, must be processed in Vietnamese, while only one ("twelve"), one ("thirty"), and two words ("thirty-four"), respectively must be processed for the corresponding French forms. On this basis, we could presume that the ADAPT model would predict higher rates of lexical errors in Vietnamese- than in French-speaking children.

Study design

To test these predictions, 68 French-speaking (FS) Belgian children and 173 Vietnamese-speaking (VNS) children from the first grade were tested. They were assessed using two transcoding tasks, verbal- and analog-Arabic. The latter was a task in which both the entry (sticks and stick bundles) and output formats (the Arabic code) were strictly the same regardless of the child's language. Each transcoding task used 1- and 2-digit numbers corresponding in French to units (U) and teen (T), decade (D), and decade-unit (DU) structures. Finally, two other numerical tasks were presented to compare the two groups of children's global mathematics level: a single-digit number comparison task and an arithmetic task. These tasks were used to control the difference in numerical abilities.

Method

The Ethics Committee of the Psychological Sciences Research Institute of UCLouvain University approved this study. All parents consented on written forms to their children's participation.

Participants

Children were recruited from six elementary schools in Vietnam and two elementary schools in Belgium's French-speaking region (Wallonia). We selected mainly children from well-developed cities in South Vietnam, namely, Ho Chi Minh City and Binh Duong, to have samples that were more comparable. In Belgium, we chose French-speaking cities that have average socioeconomic levels (Ottignies and Gembloux).

We chose Vietnamese children because, like children in many Western countries, they formally learn formal mathematics in G1 (Lê & Noël, 2021). Similarly, in Belgium, children most often approach mathematics through play activities that allow them to experiment with counting, enumeration, estimation, classification, etc. However, there is no formal teaching of the mathematical concept of symbolic addition at the preschool level (David, 2020).

All the children were tested only two months after entering first grade, so that formal schooling had just begun. This was done to reduce the impact of potentially different mathematics instruction between them. The educational program in Vietnam is identical for private and public schools because the same textbooks are used everywhere and all schools follow an identical agenda (Lê & Noël, 2020; National Assembly, 2019). At the time of the testing process, the children had been taught to identify numbers, write them, and perform addition and subtraction with numbers up to 5. At this time of the school year, the Belgian school curriculum is much the same as children are expected to master numbers to 20 by the end of the school year (David, 2020). The school year starts in mid-August in Vietnam, but on September 1st in Belgium.

Parents were requested to fill in a small questionnaire regarding the child’s development, the languages spoken, possible medical, psychological or developmental problems and whether the child followed extra-school math classes. They were also asked to indicate the highest level of education achieved by the mother and father. In Vietnam, some parents register their children,

before elementary schools, in extra-school programs that aim at stimulating mental arithmetic, such as Kumon, Mathasium or Soroban programs (Lê & Noël, 2020). This is not the case in Belgium. Based on these responses, we selected only children who were monolingual Vietnamese or French speakers. Children whose parents reported some neurodevelopmental disorders (3 Belgian and 5 Vietnamese children) or who participated in early math education programs outside the school (8 Vietnamese children) were not considered.

One hundred and seventy-three Vietnamese speakers (VNS) children (age range: 66 – 82 months, 91 boys) and 68 Belgian French speakers (FS) children (age range: 72 – 83 months, 32 boys) were tested. The two samples had a similar gender distribution, Chi-square contingency test, $X^2(1) = 0.6$, $p = .439$, but differed in terms of age (mean of 6 years 2 months, $SD = 3.93$ for the VNS and mean of 6 years 4 months, $SD = 3.29$ months for the FS, $t(239) = 4.04$, $p < .001$, $d = 0.23$. Indeed, the FS children were about 2 months older than the VNS children since their school year starts a few weeks after the school year in Vietnam.

Parents's education level was considered in terms of the number of years of schooling as the educational systems are somewhat different between the two countries (e.g., primary education is five years in Vietnam but six years in Belgium; secondary education level includes seven years in Vietnam, but six years in Belgium; professional and college education consist two to three years in Vietnam, and is similar in Belgium, but in Belgium, it is called superior education, and university in Vietnam is four years, plus possibly a master's degree of two additional years, while in Belgium, university degrees are usually five years: a bachelor's degree (three years) and a master's degree (two years). Parents' educational levels was encoded in terms of the number of years of schooling (as a continuous variable) to allow the comparison between two groups. Because the number of years of schooling does not follow a normal distribution (Shapiro-Wilk test as recommended by Ghasemi & Zahediasl, 2012; Thode, 2002), $W = .84$, $p <$

.001 for mothers, and $W = .87$, $p < .001$ for fathers, non-parametric tests were used. In each sample, both the mothers and fathers averaged 15 years of schooling, equivalent to the college education level (in Vietnam) or superior education (in Belgium). The two samples had thus quite similar level of education for the parents (for the fathers, means of 15.00 ± 2.11 for the VNS and 15.28 ± 2.02 for the FS, $U = 5785$, $z = -0.21$, $p = .837$, $r = -.01$; for the mothers: means of 14.64 ± 2.24 for the VNS and of 15.19 ± 2.92 for the FS, $U = 4708$, $z = -2.49$, $p = .013$, $r = -.16$) although French-speaking mothers's education was somewhat higher than the one from Vietnamese, but the effect size was very small.

Tasks and Stimulus

We used four paper-and-pencil tests.

Symbolic Magnitude Processing (SYMP Test). This test was developed by Brankaer, Ghesquière, and De Smedt (2016) and aims at measuring symbolic magnitude processing. The test involves two parts: number comparison and motor speed.

In the number comparison part, 60 single-digit pairs (from 1 to 9, except the ties) are presented in four columns of 15 pairs each (Verdana font, size 12). Participants are asked to color the larger of the two digits with a watercolor pen. Four practice trials are given to ensure that all the children understand the task.

In the motor speed part, the children are presented with 60 pairs of figures (circle, square, triangle, heart, star, or moon). One figure of the pair is colored black, while the other is white. The children are instructed to color the black figures as fast as possible with a watercolor pen. Two practice trials were presented to ensure that all participants understood the task.

In the original task, the time limit was 30 seconds, and the norms were collected on children tested after one semester of schooling. As the children in this study were younger and

based on the first pilot study with 42 Vietnamese first-graders (see Appendix A), we allowed them 60 seconds to answer as many items as possible for each task. The dependent variables used were the number of correct responses to the number comparison and the number of colored figures within the allocated time.

Arithmetic Task. The paper-and-pencil arithmetic task includes 13 calculations with sums ≤ 11: 2 + 2, 3 + 3, 4 + 4, 2 + 3, 4 + 2, 5 + 3, 6 + 2, 6 + 3, 7 + 2, 8 + 2, 5 + 5, 9 + 2, and 7 + 4. The task is presented on A4 paper, with the 13 trials on a page (Times New Roman font, size 14, spacing 1.5). Based on the observation of children tested with this task in the pilot study (see Appendix A), children have a maximum of 5 minutes to complete the task. They must write the answer to each calculation with their pencil. The success rates are used as the dependent variable.

Verbal-Arabic-transcoding Task. The task requires participants to write the Arabic number dictated by the experimenter. It is administered collectively to the whole class. It consists of 22 trials of 1- and 2-digit numbers. Images of animals (e.g., 22 different animals: elephant, tiger, horse) are drawn on the response sheet to help the children understand where to write each answer. There are three sets of papers to write down the numbers. The instructions were as follows: *"write the number 'three' next to the cat."* After observing that all the children finished their writing, the experimenter dictated the subsequent number. Four practice trials were given to ensure that the child understood the task. The following 22 numbers were dictated: numbers corresponding to units (2, 5, and 8), decades (10, 20, and 30), tens in French (11, 12, 13, 14, 15, and 16), and decade-unit (DU) structures (21, 25, 26, 31, 34, 35, 43, 24, 32, and 46). Items were presented in the following order: numbers 5, 2, 8, 10, 15, 26, 34, 43 (to be written on page 1), 20, 30, 13, 11, 24, 32, 46, 25 (on page 2), 16, 12, 14, 21, 35, 31 (on page 3). The success rates and error types of the transcoding tasks were used as the dependent variables.

Analog-Arabic-transcoding Task. In this task (named after a similar task used by Jarlegan, Fayol & Barrouillet, 1996), children are presented with paper sheets on which sets of sticks (one stick represents the unit and a bundle of ten sticks represents 10) are drawn. The way to present the bundle of sticks was tested in pilot studies (see Appendix A). Children are asked to write the corresponding Arabic number next to each drawing. The task contains 22 trials, corresponding to the same numbers as those used in the dictation task but presented differently. Furthermore, for half of the T and DU items, the stick bundles are presented on the left and the sticks alone on the picture's right side (i.e., typical order for the numbers 11, 13, 16, 26, 34, and 43), while for the other half, the sticks alone are presented on the left and the stick bundles on the picture's right side (i.e., reverse order for the numbers 12, 14, 15, 24, 32, and 46).

The stimuli are presented on A4 paper, with six trials per page. Each typical order trial come after three reverse order trials. To instruct the children, they are first shown real sticks, shown that ten of them made one bundle, and shown the corresponding pictures. This manipulation was introduced to help children match the real stimuli to the imaged stimuli used in the test, which helps them accurately distinguish between stick and packet quantities.

Then, they are provided with four practice trials (with both typical and reverse orders) with the correct answers to ensure that they understand the task (see Fig.1). The correct answer is coded 1, and other answers are coded 0. The correct identification of the base-10 representation for the stick bundle is encoded as 1; all other answers are encoded as 0. The dependent variables used are the analog-Arabic-transcoding task's success rates (among 22 trials) and the success rates for base-10 consideration (for the 19 trials of the task, as the three trials corresponding to the unit structure are not considered here).

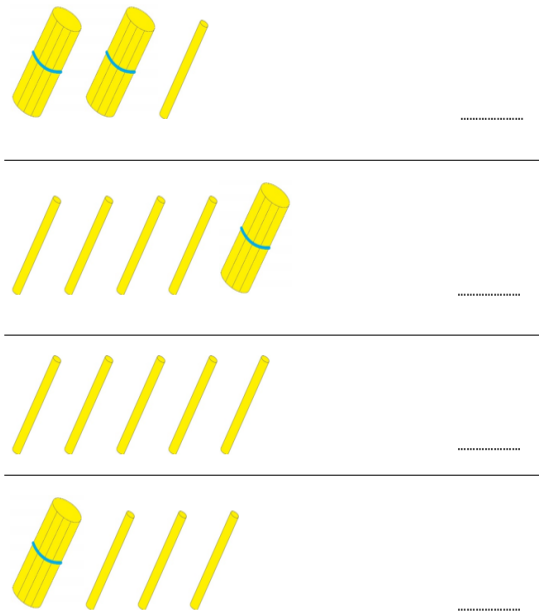


Fig. 1. Examples of the analog-Arabic-transcoding task in the official testing process

Procedure

This study was conducted on two phases: two pilot studies, reported briefly in Appendix A and the formal test, which is reported below.

The children were tested collectively in a quiet room in their school in a session of 25 minutes. They sat one per table to avoid peeking and were recommended to cover their answers with their hands when they were done. The tasks were administered in the following order: motor -speed, verbal-Arabic-transcoding, analog-Arabic-transcoding, number-comparison, and arithmetic. The official testing process was conducted in November in Vietnam and in December in Belgium because schools open in Belgium (September) one month later than they do in Vietnam (August). The data collection processes in Vietnam and Belgium were realized by two Vietnamese and two Belgian experimenters.

Transcoding Error Analysis

Errors were categorized as lexical or syntactic (following Deloche & Seron, 1982a; 1987; Moeller et al., 2015).

Lexical errors concern the substitution of one or more lexical elements by another without modifying the number's global structure. This error category is further subdivided into (a) *lexical errors in the zero position* (**L0),** e.g., "twenty"—2**0** → 2**1**; (b) *lexical errors in the unit position* (**LU**), e.g., "twenty-six"—2**6** → 2**5**; (c) *lexical errors in the decade position* (**LD)**, e.g., "thirteen"—**1**3 → **3**3; or (d) *lexical class errors* (**LC**), e.g., thirteen"—1**3** → **3**0. Lexical class errors occurred in French but not in Vietnamese. In contrast, Vietnamese's lexical errors could result from the inversion of the lexical primitives "ten" and the unit, e.g., "ten two"—12 → "two ten"—20. Lexical errors that could not be classified into one of these categories were coded as (f) other lexical errors (**L-Other**).

Errors were classified as syntactic when they altered the produced numeral's syntactic structure compared to the target form. Syntactic errors could either be due to violations of the (a) *additive composition rule* (**S+)**, e.g., in Vietnamese, "two-ten-five" = "hai mươi lăm"—(for 25) → 205 (when five is appended in the composition rather than added); (b) *multiplicative composition rule* (**Sx)**, e.g., "two-ten-five" (for 25) → 215 (when ten is appended to the composition rather than multiplied); and (c) *additive and multiplicative composition* (**S+x)**, e.g., "two-ten-five" (for 25) → 2105 (2 x 10 + 5). Further, (d) *inversion errors* (**S-I**) were categorized as syntactic errors when the unit and decade digits were inverted, e.g., "forty-six" → 64 or as (i) *syntactic errors with the omission of value in the unit or decade position* (**S-Omission**), e.g., "twenty-four"—2**4** -> 2 or "thirty-four"—**3**4 -> 4. Again, errors that could not be classified into these subcategories were coded as (f) other syntactic errors (**S-Other**).

For the classification of transcoding errors, we followed a multi-person procedure: the first author coded all transcoding errors, and then, these errors were checked by the second author and the experimenter who participated in the testing. They discussed and agreed on the above error classification.

Misunderstanding of the Base-10 Representation

In the analog-Arabic-transcoding task, misunderstanding of the base-10 material (i.e., the stick bundle) was encoded as **D4** when the child erroneously counted the visible sticks in the bundle and thus considered the bundle as four units (e.g., two bundles and one stick were transcoded as 9 (4 + 4 + 1)) or as **D1** when the child erroneously considered the bundle as 1 unit (e.g., three bundles and five sticks were transcoded as 8 (1 + 1 + 1 + 5)). If the child misunderstood base-10 or erroneously identified base-10 as D4 or D1 and violated the lexical or syntactical rule mentioned above, (e.g., 2D6U (for 26) → 104 (i.e., 4 + 4 + 6 = 14)) combined with a syntactic error of additive composition), it was encoded only as D4 or D1 without an error nature analysis.

Results

The analyses were run on SPSS version 25.0.

Preliminary Analyses

Task reliability and distribution, gender effects and general comparison of the two samples

The children's motor speed task did not follow a normal distribution, $W = .76$, $p < .001$. Non-parametric tests indicated that Vietnamese and French-speaking children had similar motor speed, $U = 6292$, $z = -1.89$, $p = .059$, $r = -.04$ (means of 50.42 ±12.78 for VNS and 53.03 ± 12.78 for FS).

The Cronbach's alpha was calculated on each of the three tasks developed in this study to assess their internal consistency. Good reliability coefficients were found for the verbal-Arabic-transcoding (α = .93 for both samples; α = .96 for FS, α = .89 for VS), the analog-Arabic-transcoding (α = .97; α = .97; α = .96, respectively), and the arithmetic tasks (α = .84; α = .75; α = .88).

The success rates followed a normal distribution for number comparison but not for the other three main numerical tasks, $W = .99$, $p = .216$ for number comparison task, $W = .70$, $p < .001$ for verbal-Arabic-transcoding, $W = .88$, $p < .001$ for analog-Arabic-transcoding and for arithmetic tasks, $W = .69$, $p < .001$. Therefore, non-parametric tests were used for the variable with a non-normal distribution.

Success rates on numerical tasks were similar for boys and girls (Table 3).

Table 3

Comparison of Success Rates on the Numerical tasks according to the child's gender

	Mean ± SE (%)		
Numerical tasks	Girls (*N*=118)	Boys (*N*=123)	Gender effect
Motor speed	88.35 ± 1.59	82.49 ± 1.96	$U = 8221$, $z = -1.89$, $p = .059$, $r = -.12$
Number comparison	46.34 ± 1.18	45.20 ± 1.27	$t(239)$, $p = .514$, $d = .92$
Addition	83.86 ± 1.73	83.55 ± 2.24	$U = 6968$, $z = -0.56$, $p = .572$, $r = -.04$
Verbal-Arabic-transcoding	87.86 ± 2.22	87.63 ± 2.25	$U = 7225$, $z = -0.06$, $p = .949$, $r = -.01$
Analog-Arabic-transcoding	58.08 ± 3.01	58.94 ± 2.99	$U = 7118$, $z = -0.26$, $p = .796$, $r = -.02$

Cross-national variation in general numerical performance

The success rates on the four numerical tasks were compared between the two language groups using a *t*-test for number-comparison and non-parametric Mann-Withney tests for addition, verbal-Arabic-transcoding and analog-Arabic-transcoding.

The Vietnamese- and French-speaking children did not differ on the number-comparison but differed on both the transcoding and addition tasks (Table 4) with the higher effect size on the verbal-Arabic transcoding task and the smaller effect size on addition tasks. This result supports the hypothesis that a transparent number-naming system positively affects transcoding abilities. Unexpectedly, this advantage is also present when the input and output formats are the same for the two groups (Fig. 2).

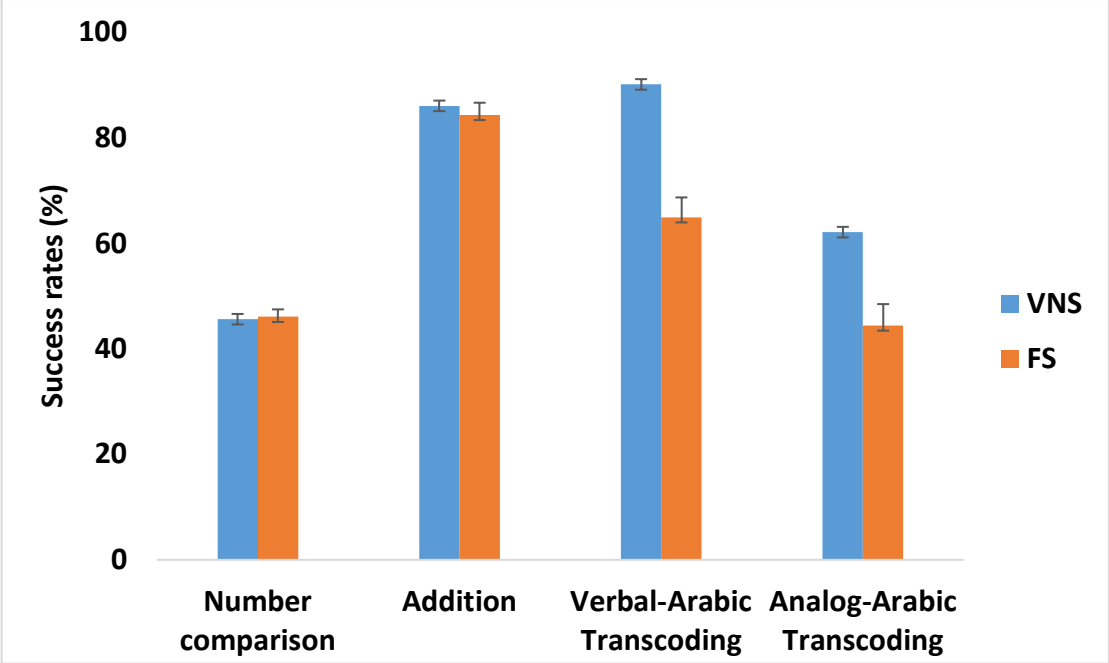


Fig. 2. Comparison of the success rates by task and language-speaking group (error bars represent standard errors)

Table 4

Comparison of Success Rates on the Numerical tasks by Group

Tasks	Mean ± SE (%)		Language effect
	VNS	FS	

Number comparison	45.62 ± 1.08	46.10 ± 1.39	$t(150.32)$, $p = .788$, $d = .04$
Addition	86.08 ± 1.77	84.39 ± 2.29	$U = 4780$, $z = -2.39$, $p = .017$, $r = -.15$
Verbal-Arabic-transcoding	90.15 ± 1.33	64.97 ± 3.75	$U = 2911$, $z = -6.65$, $p < .001$, $r = -.43$
Analog-Arabic-transcoding	62.13 ± 2.46	44.45 ± 4.04	$U = 4033.5$, $z = -3.82$, $p < .001$, $r = -.25$

Analysis plan

The subsequent analyses focus on a deeper exploration of the language effect on the transcoding performance and error nature. As we were interested in testing interactions between groups and the structures of the items, repeated-measures ANOVA were conducted as *F*-test is quite robust to the non-normality of the variables (Blanca et al., 2017). Yet, the obtained results were confirmed by non-parametric analyses. If the sphericity assumption was violated, the corrected degrees of freedom, together with the respective Greenhouse-Geisser coefficients (GGs) or Huynh-Feldt coefficients (HFs), were reported when epsilon < .75 or > .75 (Field, 2018). Gender was not introduced into the analyses because neither the effect of gender was significant (all *p*s > .05) and because we had no hypotheses regarding possible gender effects.

Verbal-Arabic-transcoding performance and error analysis

Verbal-Arabic-transcoding performance according to the structure of the verbal input code

Table 5 shows the average success rates (i.e., number of correct answers x 100 divided by the number of items presented) and standard error (SE) on the Verbal-Arabic-transcoding task of the Vietnamese- and French-speaking children for each verbal number structure.

Table 5

Success Rates on the Verbal-Arabic-transcoding task by Structure and Language

Structures	Mean ± SE (%)	
(items in parentheses)	VNS	FS
U (2, 5, and 8)	98.65 ± 0.69	99.02 ± 0.69

D (10, 20, and 30)	92.87 ± 1.55	84.56 ± 3.44
T (11–16)	92.1 ± 1.59	78.26 ± 3.71
DU (21, 25, 26)	88.67 ± 1.74	53.52 ± 5.09

Note. units (U) and teen (T), decade (D), and decade-unit (DU) structures

To examine whether the Vietnamese- and French-speaking children were sensitive to their number language system's particularities, the success rates were tested by a 2 (languages, between-subject factor) x 4 (structures: U, D, T, and DU, within-subject factor) ANOVA with repeated measures on the last factor. Consistent with the previous analysis, the main effect of language was significant, $F(1, 239) = 37.73$, $p < .001$, $\eta^2 = .136$. The main effect of the structure of the verbal number was also significant, $F(2.81, 670.53) = 77.30$, $p < .001$, $\eta^2 = .244$, HF = 0.94. The interaction of structure x language was also significant, $F(2.81, 670.53) = 33.56$, $p < .001$, $\eta^2 = .123$, HF = 0.94 (Fig. 3).

A non-parametric Friedman test was conducted to compare the 4 structures and confirmed the significant difference reported in the ANOVA, $X^2 = 136.26$, $p < .001$. The Wilcoxon matched-pairs signed-ranks test (using a Bonferroni correction for multiple comparison, thus alpha was set at .012) showed that success rates on the U structure were the highest (all ps < .001), Unit vs. Decade: $z = -5.01$, $p < .001$, $r = -.32$; Unit vs. Teen: $z = -6.04$, $p < .001$, $r = -.39$; Unit vs. Decade-Unit: $z = -8.24$, $p < .001$, $r = -.53$. The T structure success rates were similar to the D structure, $z = -1.45$, $p = .147$, $r = -.09$, and the D structure success rate was higher than the DU structure, $z = -5.86$, $p < .001$, $r = -.38$.

The language by structure interaction was examined by comparing the two language groups for each structure, using non-parametric Mann-Whitney tests. For the Unit structure, both groups performed similarly, $U = 5880$, $z = -.014$, $p = .989$, $r = -.001$. However, for the D, T and DU structures, the VNS children performed better than the FS children, $U = 5039$, $z = -2.73$, $r =$

.18, $p = .006$; $U = 4269$, $z = -4.51$, $p < .001$, $r = .29$; $U = 3041$, $z = -6.51$, $p < .001$, $r = .42$, respectively.

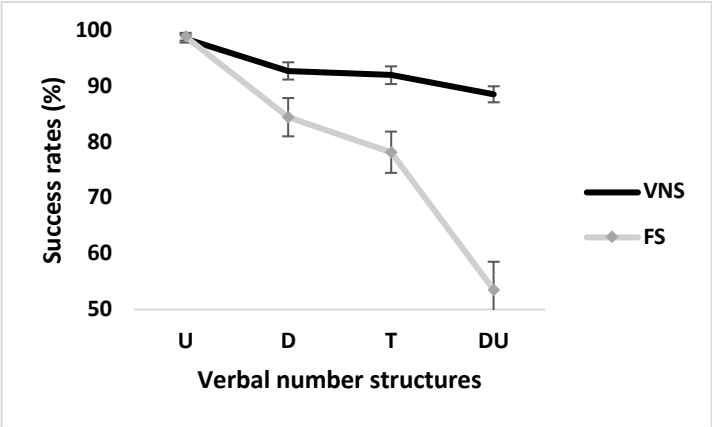


Fig. 3. Success rates according to the structure of verbal numbers (error bars represent standard errors).

Verbal-Arabic-transcoding error

Table 6 shows the error frequency for each error category.

Lexical and syntactic errors in the verbal-Arabic-transcoding task. Non-parametric Mann-Withney tests were carried out to compare the two groups for each type of error produced during verbal-Arabic transcoding (a Bonferroni correction was applied for multiple comparison and thus alpha was set at .025). The French-speaking children committed significantly more lexical errors than the Vietnamese-speaking children, $U = 3436$, $z = -5.77$, $p < .001$, $r = -.36$. However, the two samples did not differ in their syntactic error rates, $U = 5752$, $z = -0.37$, $p = .712$, $r = -.02$. These results supported the hypothesis that the FS children would commit more lexical errors.

Lexical error subcategories in the verbal-Arabic-transcoding task. To go even deeper, the two samples were compared in their error rates in each of the five lexical error subcategories (L0, LU, LD, LC, and L-Other) using Mann-Withney tests (a Bonferroni correction was applied

for multiple comparison and thus alpha was set at .01). The result showed that the French-speaking children committed significantly more lexical errors related to the unit position (LU, e.g., 16 → 15), $U = 4734$, $z = -3.26$, $p = .001$, $r = -.21$, the decade position (LD, e.g., 14 → 24), $U = 3506$, $z = -7.31$, $p < .001$, $r = -.47$, class errors (LC, e.g., 13 → 30), $U = 4853$, $z = -3.63$, $p < .001$, $r = -.23$) and other (L-Other), $U = 4683$, $z = -4.12$, $p < .001$, $r = -.26$ than the Vietnamese-speaking children. The groups did not differ in the zero-related lexical errors (e.g., "twenty"- 20 → 21), $U = 5780$, $z = -0.58$, $p = .562$, $r = -.04$.

Table 6

Overview of the Error Rates for both of the Transcoding tasks: the Overall errors (A) and Subcategories of Lexical (B) and Syntactic errors (C); Misunderstanding of base-10 (D) only for the Analog-Arabic-transcoding task

Error categories	Verbal-Arabic-transcoding				Analog-Arabic-transcoding			
	VNS		FS		VNS		FS	
	(*n*)*	%*	*n*	%	*n*	%	*n*	%
(A) Overall errors								
Lexical errors	121	**3.18**	233	**15.57**	323	**8.49**	212	**14.17**
Syntactic errors	152	**3.99**	32	**2.13**	58	**1.52**	141	**9.43**
(B) Subcategories of lexical errors								
L0	10	**0.26**	4	**0.27**	8	**0.21**	4	**0.27**
LU	53	**1.39**	52	**3.48**	80	**2.10**	54	**3.61**
LD	15	**0.35**	103	**6.89**	108	**2.84**	49	**3.28**
LC	22	**0.58**	33	**2.21**	36	**0.95**	27	**1.81**
L-Other	21	**0.55**	41	**2.74**	91	**2.39**	78	**5.21**
(C) Subcategories of syntactic errors								
S+	69	**1.81**	0	–	7	**0.18**	6	**0.4**
Sx	12	**0.32**	0	–	0	–	0	–
S+x	2	**0.05**	0	–	1	**0.03**	0	–
S-I	15	**0.39**	12	**0.8**	22	**0.58**	9	**0.6**
S-Omission	42	**1.10**	9	**0.6**	18	**0.47**	100	**6.68**
S-Other	12	**0.32**	11	**0.74**	10	**0.26**	26	**1.74**
(D) Misunderstanding of Base-10	–	–	–	–	586	**17.83**	272	**21.05**
Total errors (A + D)	273		265		967		625	

Note..(n)* stands for frequency and % corresponds to the number of errors of this type observed in the sample x 100 divided by (number of items x number of participants in the sample)

We hypothesized that the learning of teen and decade words would challenge the FS children. We expected that, regarding the T structure, they would especially produce an error on the unit position (LU), while for the DU structure, they would mainly produce errors in the decade position (LD), but that these differences should not appear for the VNS children. To test these hypotheses, we conducted Wilcoxon matched-pairs signed-rank tests separately for each group. As expected, when transcoding T numbers, the FS children produced six times more LU than LD errors (36 errors, 8.82% vs. 6 errors, 1.47%, respectively, $z = -3.38$, $p = .001$, $r = -.41$; while for the DU structures, they produced nine times more LD (64 errors, 15.69%) than LU errors (7 errors, 1.71%), $z = -3.98$, $p < .001$, $r = -.48$. In contrast, this difference did not appear for the VNS children when transcoding the number with the DU structures (9 LU vs. 9 LD; $z = -0.3$, $p = .976$, $r = -.02$) while for the T structures, the VNS children committed more LU (0.77%) than LD errors (0.19%); $z = -2.12$, $p = .034$, $r = -.16$ but this difference was rather small (8 LU vs. 2 LD).

Thus, the results support our hypothesis that the French number-naming system's larger lexicon led to more lexical errors, in particular, due to confusion among the decade (thus resulting in more LD errors) and teen words (resulting in more LU errors).

Syntactic error subcategories in the verbal-Arabic-transcoding task. Regarding the syntactic errors (see Table 6), of course, the FS children never produced Sx or S+X errors, as none of the verbal structures proposed involved any multiplicative relations. However, surprisingly, they also never produced any S+ errors. By contrast, the VNS children produced all of these types of errors, with the majority being S+ errors.

The Wilcoxon test showed that the VNS children made more additive composition errors (S+) than the other types of error: Sx: $z = -3.01$, $p = .003$, $r = -.23$; S+x: $z = -3.63$, $p < .001$, $r = -$

.28; S-I (inversion error): Z = -2.81, p = .005, r = -.21; and other syntactic error (S-Other): z = -3.55, p < .001, r = -.27. However, the S+ error rates were not significantly higher than the omission syntactic (S-Omission) error rates, z = -1.01, p = .314, r = -.08 (Table 6).

The VNS children performed better than the FS children did on the T and DU structures (but not on the U and D structures). The FS children committed more lexical errors than the VNS children did, especially LU, LD, and LC errors. Interestingly, their lexical errors were more often related to the unit position for the T structure and the decade position for the DU structure. However, this difference in DU transcoding did not appear for the VNS children. Finally, although neither group differed in syntactic error rates, the VNS children produced only S+, Sx, or S+x errors, with most of the syntactic errors related to the additive composition.

Analog-Arabic-transcoding performance and error analysis

Analog-Arabic-transcoding performance according to the structure and order of the analog stimuli

Table 7 shows the means and standard errors for the analog-Arabic correct rates according to the order and structure of the analog number input.

Success rates on the Analog-Arabic transcoding performance was first analyzed using a repeated measures ANOVA with a 2 (languages) x 4 (structures: U, D, T, and DU) model. The main effect of language was significant, $F(1, 237) = 18.07$, $p < .001$, $\eta^2 = .84$, indicating that the success rates were lower in the FS than in the VNS children (as shown earlier, 44.45 ± 4.04 vs. 62.14 ± 2.46, respectively). The effect of structure was also significant, $F(2.34, 555.74) = 168.39$, $p < .001$, $\eta^2 = .415$, HF = 0.78 (Table 8) as well as the interaction of structure x language, $F(2.34, 555.74) = 9.05$, $p < .001$, $\eta^2 = .037$, HF = 0.78 (Fig. 4).

Table 7

Success Rates in the Analog-Arabic-transcoding task by Structure and Order.

Structures and orders	Mean ± SE (%)			Comparisons
	Both samples	VNS	FS	
Units	96.96 ± 1.25	97.88 ± 1.57	94.60 ± 1.92	$U = 5681$, $z = -0.74$, $p = .458$, $r = -.05$
Decades	96.86 ± 2.39	66.09 ± 2.71	47.54 ± 4.59	$U = 4280.5$, $z = -3.44$, $p = .001$, $r = -.22$
T (Teens)	63.62 ± 2.51	70.33 ± 2.77	46.56 ± 4.88	$U = 3943.5$, $z = -0.74$, $p < .001$, $r = -.05$
T in typical order	64.59 ± 2.6	71.86 ± 2.86	46.08 ± 5.03	$U = 3789$, $z = -4.62$, $p < .001$, $r = -.30$
T in reverse order	62.66 ± 2.6	68.78 ± 2.88	47.06 ± 5.14	$U = 4227.5$, $z = -3.64$, $p < .001$, $r = -.23$
DU (Decade-Unit)	43.61 ± 2.68	48.84 ± 3.17	30.29 ± 4.69	$U = 4372$, $z = -3.17$, $p = .001$, $r = -.20$
DU in typical order	39.56 ± 2.84	50.7 ± 3.16	31.72 ± 4.73	$U = 4617$, $z = -2.82$, $p = .005$, $r = -.18$
DU in reverse order	45.35 ± 2.68	44.51 ± 3.41	26.96 ± 4.85	$U = 4393$, $z = -3.14$, $p = .002$, $r = -.20$

These results were then confirmed by non-parametric analyses. The performance of the two groups were compared using Mann-Withney tests for each of the four structures (U, D, T, DU), using a Bonferroni correction for multiple comparisons and thus setting alpha at .0125 (see Table 8). The result showed that the groups performed equally well on the U structure (U = 5681, Z = -0.74, p = .458, r = -.05). For the three other structures, Vietnamese-speaking children performed significantly better than the French-speaking children did, D structure: U = 4280.5, z = -3.44 , p = .001, r = -.22, T structure: U = 3943.5, z = -0.74 , p < .001, r = -.05, DU structure: U = 4372, z = -3.17 , p = .001, r = -.20 (Fig.4).

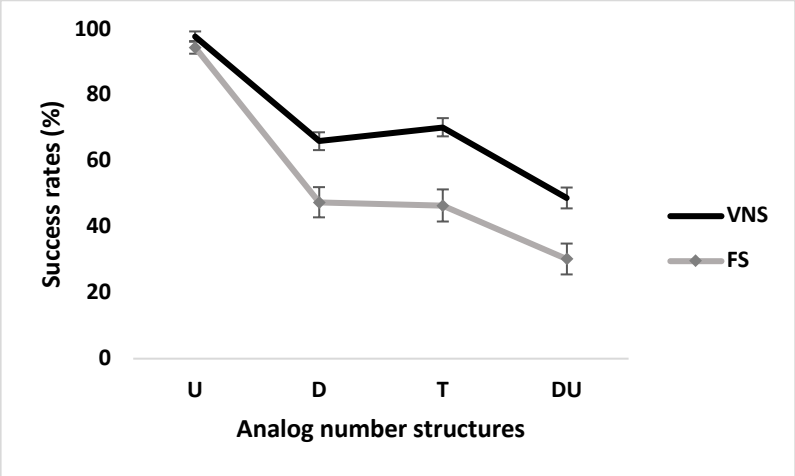


Fig. 4. Success rates according to the structure of the analog-Arabic-transcoding task (error bars represent standard errors).

To examine whether the VNS and FS children were sensitive to the order of the analog stimulus, success rates were entered in a 2 (languages, between-subject factor) x 2 (orders: typical and reverse) x 2 (structures: T, DU) ANOVA with repeated measures on both of last factors (orders and structures). The main effect of language was significant, $F(1, 239) = 22.04$, $p < .001$, $\eta^2 = .084$ (VNS children had higher success rates than the FS children did). The structure effect was also significant, with the T structure's success rates being higher than the DU's, $F(1, 239) = 67.87$, $p < .001$, $\eta^2 = .221$, HF =1.00. However, the order effect was not significant, F(1,

239) = 2.59, p = .108, η^2 = .011, HF =1.00, and neither were any of the interactions (all ps > .05; Fig. 5).

Non-parametric tests were used to confirm these results. A Friedman test comparing the 2 orders (typical and reverse) across the entire sample revealed a significant difference, X^2 = 12.7, p < .001, indicating that overall success rates were higher for typical order (54.96 ± 38.38) than reverse order (51.11 ± 39.22).

Wilcoxon tests were then conducted separately for each language sample and each structure (T and DU) to compare the success rate for the typical order or reverse order. For the VNS children, the success rates for typical order were higher than for reverse order in the T structure, 71.86% vs. 68.78%, z = -2.12, p = .026, r = -0.17 and the DU structures, 50.7% vs. 44.5%, z = -3.97, p < .001, r = -0.48). In contrast, for the FS children, the success rates in the T structure, did not differ significantly between the two orders, z = -0.71, p = .478, r = -0.05; whereas, for the DU structure, the success rates for typical order were higher than for reverse order, z = -2.37, p = .018, r = -0.29.

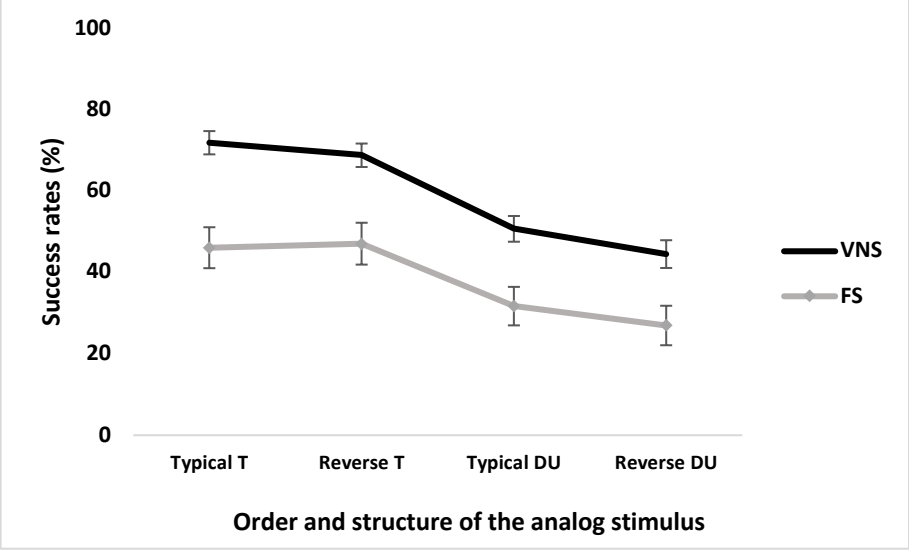


Fig. 5. Success rates according to the order structure of the analog-Arabic-transcoding task (error bars represent standard errors).

Analog-Arabic-transcoding errors

Non-parametric Mann-Withney tests were then carried out to investigate whether the two groups differed in terms of their overall lexical, syntactic and base-10 error rates (Bonferroni correction was applied, setting the alpha at .017). These analyses showed that the FS children committed significantly more lexical, $U = 4715$, $z = -2.45$, $p = .014$, $r = -.16$ and syntactic errors, $U = 4715$, $z = -4.32$, $p < .001$, $r = -.28$ than the VNS children. Both groups marginally differed on base-10 error rate, $U = 4778$, $z = -2.49$, $p = .013$, $r = -.16$ (Table 6).

To resume, in the analog-Arabic-transcoding task, we found that the VNS children performed better than the FS children did on all the structures D, T, and DU but not on the U structure. The FS children committed more lexical, syntactic errors and base-10 errors than the VNS children did. However, the difference in base-10 errors is marginal. Finally, the performance of both groups was affected by reversing the order of the stimuli.

Language effect with control variables

To examine whether the difference between the two language groups in the transcoding tasks were not explained by overall differences in arithmetic skills, age, or, for the analog-Arabic transcoding task, by a difference in the understanding of the base-10 material, ANCOVAs were run controlling for these factors. Success rates for verbal-Arabic transcoding were entered into an ANCOVA with language as a between-subjects factor and success rates on addition and age (in months) as two covariates. The effect of language remained significant with better performance for VNS children, $F(1, 237) = 79.81$, $p < .001$, $\eta 2 = 0.252$. A similar analysis was run on the success rates of analog-Arabic transcoding with the same two covariates plus the errors rates for base-10 material understanding as covariates. The effect of language was still significant and

showed that the VNS children performed better than the FS children, $F(1, 236) = 17.91$, $p < .001$, $\eta 2 = 0.071$.

Discussion

The current study reexamined the influence of language characteristics on transcoding performance. Specifically, we examined the influence of the base-10 transparency of the number-naming system on children's transcoding performance and error nature. We also examined whether this influence could still be observed when the transcoding task does not involve verbal numbers, as in the analog-Arabic-transcoding task. For these purposes, we tested children speaking Vietnamese or French.

To minimize the possible impact of differences in mathematics instruction across countries, we selected young first-grade students who had attended primary school for only two months and also excluded children who attended extra-math course outside of school. Furthermore, the two groups were similar in terms of gender, motor speed, single-digit number comparison skills, and parental education level (although the FS mothers' education was half a year higher than the one of VNS). Consistent with previous studies (Geary et al., 1993; Rodic et al., 2015), we found that the VNS children had better arithmetic skills than the FS children, but the effect size of this difference was very small, $r = -.15$, and smaller than the moderate to large effect size reported in comparing Chinese and American children, Cohen's $f = 1.03$, (Geary et al., 1993) and in the comparison of Chinese and British children, $\eta^2 = .126$ (Rodic et al., 2015). Despite their high degrees of comparability and even controlling for the covariates (arithmetic skills, age and understanding of base-10 material), we found a significant difference between the two groups in both transcoding tasks with the highest effect size ($r = -.43$) on verbal-Arabic transcoding and following by Analog-Arabic transcoding ($r = -.25$). The VNS children performed higher than the FS children did on both the verbal- and analog-Arabic-transcoding tasks. This

finding is consistent with previous studies (Moeller et al., 2015; Nguyen & Grégoire, 2014). Previous studies have shown that regular number naming systems facilitate the numerical development of young children. In particular, such systems favor the counting development of Asian preschoolers (Lê & Noël, 2020; Lonneman et al., 2019; Miller et al., 1995; Miller & Stigler, 1987; Rodic et al., 2015; Xu & LeFevre, 2018), the base-10 representation of numbers (Miura et al., 1988; Miura & Okamoto, 1989; Miura et al., 1993; Miura et al., 1994; Saxton & Towse, 1998) and place-value understanding (Bahnmueller et al., 2018, for a review; Miura et al., 1994). Here, we found that it also has advantages for children's transcoding abilities.

Advantage of the base-10 transparent number-naming system on the verbal-Arabic-transcoding task

The VNS children showed a higher success rate on the verbal-Arabic-transcoding task at the beginning of the first grade, although they have not formally learned Arabic numbers beyond 10 (i.e., the curricula's program for both samples is equal, for instance, only teaching Arabic numbers until 5 at the testing time). This advantage can be accounted for by the semantic transcoding model of McCloskey et al. (1985), which assumes that the base-10 transparency of the Vietnamese number-naming system would facilitate the necessary activation of the base-10 semantic representation of the numbers to transcode.

Differences were observed between the FS and VNS children for the T and DU structures but not for the U and D structures. Overall, the FS children committed more lexical errors than the VNS children did, both class errors ("Treize", 13 → "Trente", 30) and errors related to the position information of the lexical primitive (errors on the unit position for the T structures, e.g., 12 → 14 and errors on the D position for the DU structures, e.g., 25 → 35). Our results align with

the previous finding (Moeller et al., 2015) that German-speaking children committed more lexical class errors and inversion errors than Japanese-speaking children.

According to the ADAPT model (Barrouillet et al., 2004), lexical errors are due to storage difficulty, which depends on the number of syllables in the sequence or difficulties in retrieving the digital forms from LTM. As we used numbers with similar syllable lengths in both languages, this factor cannot explain the observed difference. However, transcoding from Vietnamese verbal numbers requires more steps in terms of "forms to retrieve from LTM" than French verbal numbers do (except for the U structure) (see Appendix B). Therefore, we presumed that the ADAPT model would predict a higher rate of lexical errors among the VNS than the FS children, which was not the case. The critical factor accounting for the difference in lexical errors produced is thus not related to the number of steps required to "find the primitive verbal form from LTM." Instead, the crucial factor at this age seems to be the extent of the numerical lexicon that the child must learn. While only Unit words (from one to nine) and the word ten have to be learned by VNS children, FS children have to learn the unit words, the Teen words (from eleven to sixteen) and the Decades words (from ten to ninety). Accordingly, FS children produced more lexical errors than the VNS children did. At that age, FS children still confuse the different Teen and Decade words. This observation is similar to the one of Barrouillet et al.'s (2004) who showed that learning lexical primitives poses difficulties in French first graders but are no longer a challenge for second and third graders.

Another point regarded the syntactic errors: both the Power and Dal Martello (1990, 1997) and the ADAPT models (Barrouillet et al., 2004) predicted that the VNS children would produce more syntactic errors than the FS children. According to the former, Vietnamese verbal numbers involve more additive and multiplicative relations than French verbal numbers do. This situation is because Vietnamese number transcoding requires the processing of more transcoding

695 rules than French number transcoding does, and syntactic errors are due to algorithmic
696 transcoding failures. However, this was not the case. Both groups of children produced a similar
697 rate of syntactic errors. Nevertheless, we found that the VNS children produced only S+, Sx, or
698 S+x errors, with most syntactic errors related to the additive composition (69 S+ errors among
699 152 syntactic errors). Our finding is consistent with a previous study, which showed that 7-year-
700 old Italian-speaking children mainly produced overwriting errors (related to the additive
701 relationship) (Power & Dal Martello, 1990).

702 Thus, the difference between VNS and FS children did not conform to the prediction of
703 the ADAPT^{BASIC} model (Barrouillet et al., 2004). However, this model has been developed to
704 account for the transcoding of young children who are learning numbers from 1 to 99. According
705 to Barrouillet et al. (2004), after having been transcoding 2-digit numbers quite frequently,
706 children begin to memorize the forms produced by the transcoding. Progressively, the full 2-digit
707 form is retrieved directly from long-term memory. This more advanced state of the model is
708 called the ADAPT^{ADV}. Along with this view, one could propose that the numerical development
709 of VNS children is faster than the one of FS children and, in particular, that while FS children are
710 still following the ADAPT^{BASIC} model, VNS children might already be using the ADAPT ^{ADV}
711 model. If this were the case, they would easily transcode all 2-digit numbers by simply retrieving
712 the form from LTM. This could then account for their better performance relative to FS children,
713 especially for numbers with DU structure.

714 In sum, the better transcoding performance of VNS children could be due to their more
715 transparent base-10 number naming system or to their more restricted primitive lexicon (both
716 going together).

Advantage of the base-10 number-naming system for the analog-Arabic-transcoding task

In the analog-Arabic-transcoding task, the VNS children outperformed the FS children. This observation was not expected on basis of McCloskey's (1985) model, which predicted no difference between the two groups in this task where the input and the output codes are strictly similar. Nor can this difference be explained by a difference in familiarity with the analog material used here, since none of the children in the two groups had learned this representation of numbers at school. The VNS children produced slightly fewer errors in understanding base-10 stimuli than the FS children, suggesting that their transparent base-10 number system facilitates their understanding of the base-10 system (as already reported using other tasks by Miura et al., 1994). Yet this difference was only marginal and did not explain the large difference observed in this transcoding task by the two groups. So how can these results be explained? None of the transcoding models presented were developed to account for this type of task.

To explain this difference, we propose that the analog-Arabic-transcoding task actually requires three steps: (1) comprehension of the base-10 material represented, (2) activation of the corresponding verbal number in the phonological buffer (e.g., "these are one, two, three bundles, which is thirty and one, two sticks, so thirty-two sticks"), (3) transcoding of this verbal number into the corresponding Arabic number. In this view, the difference observed in this analog-Arabic transcoding between the two groups would be due to the fact that the intermediate verbal representation activated through the enumeration of the analog material is different. Accordingly, in the analog-Arabic-transcoding task, we found the same difference in performance between the two groups as that observed in the number dictation task.

We also observed, in both groups, that the transcoding performance in this task was lower than the one observed in the verbal-Arabic-transcoding task. This result could simply be because

741 understanding the material and activating the corresponding verbal number representation is an
742 additional step that may lead to errors beyond those occurring in verbal-Arabic-transcoding tasks.

743 **Limitations and perspectives**

744 Our study has some limitations. To ensure that the children remained attentive, we limited
745 the testing process to four tasks that took 25 minutes. Further studies might consider adding
746 working memory assessments, as they have been shown to influence transcoding performance
747 (see Camos, 2008; Imbo et al., 2014; Moura et al., 2013). Moreover, further studies might
748 examine whether the transparent base-10 Vietnamese number-naming system supports better
749 numerical comprehension. Our 1-digit Arabic-number-comparison task does not address this
750 question. In addition, this task could reflect a ceiling effect with the single-digit number
751 comparison task. Future studies should include a two-digit number comparison task and also a
752 verbal number comparison task with the same numbers to test whether the understanding of these
753 numbers and access to their magnitude representation is similar or different across languages. It
754 might also be interesting to add a task that tests children's number lexicon, for example by asking
755 them to count as far as they can.

756 Moreover, there are possible differences between the two groups that may have affected
757 performance in the transcoding tasks, such as children’s attitudes toward computation and
758 mathematics, numerical stimulation at home (Huntsinger et al., 1997; Skwarchuk et al., 2014;
759 Berkowitz et al., 2015; Gunderson & Levine, 2011; Levine et al., 2010; Saxton & Towse, 1998)
760 and class sizes difference (Parandekar & Sedmik, 2016). Due to the young population, class sizes
761 in Vietnam are still quite large, averaging 38 students per class (Nguyen et al., 2020, for a review;
762 Parandekar & Sedmik, 2016). However, in Belgium, class sizes are smaller with about 13
763 students (OECD, 2019). In this study, we did not measure the home numeracy, yet a previous

764 study (Lê & Noël, 2020) on very similar Vietnamese and Belgian samples found only slight
765 difference of home numeracy between these two groups of children.

766 Although we applied two criteria to select comparable samples, such as location (large
767 cities) and parental education, we did not measure parental socioeconomic level. However,
768 Davis-Kean (2005) found direct effects of parental education (but not income) on the
769 standardized educational outcomes of European American children. In addition, incomes are
770 higher in Europe than in Asia (Yong, 2019); however, Vietnam's rapid economic growth over the
771 past 30 years has transformed it from one of the poorest countries in the world to a middle-
772 income country (World Bank, 2013). Furthermore, it could not be directly compared because the
773 cost of living is very different between the two countries (Lê & Noël, 2020).

774 **Summary and conclusion**

775 In summary, several of the hypotheses issued from the different transcoding models were
776 not supported by the data.

777 First, although Vietnamese verbal numbers use more syntactic relations than the
778 corresponding French verbal numbers, the VNS children did not produce higher rates of syntactic
779 errors than the FS children did. This result is not consistent with the prediction made by the
780 Power and Dal Martello (1990, 1997) or ADAPT^{BASIC} model (Barrouillet et al., 2004).

781 Second, although Vietnamese verbal numbers require more steps for form retrieval from
782 LTM, we failed to observe more lexical errors in the VNS children, as predicted by the
783 ADAPT^{BASIC} model (Barrouillet et al., 2004). Instead, we found that FS children produced more
784 lexical errors . We argue that at this age, a critical factor is the extent of the numerical lexicon.
785 Indeed, FS children must learn specific number words for T and D, which is not the case for VNS

786 children. For these number words, errors were reported related to the class or the position
787 information (as described by Deloche and Seron, 1982a, 1982b).

788 Third, the advantage found in the number-dictation task for the VNS children could be
789 explained by their more transparent base-10 system, which more easily activates the base-10
790 semantic representation of the number for the transcoding process, as assumed by McCloskey et
791 al. (1985). However, the base-10 misunderstanding errors observed in the analog-Arabic-
792 transcoding task differed only marginally between the two groups with VNS children producing
793 slightly less of these errors than FS children. Accordingly, we rather propose that the advantage
794 observed in VNS children is essentially due to the fact that their number system has a more
795 limited vocabulary. This could indeed explain why difference mainly concerns lexical errors,
796 with FS children producing more of these as they continued to be challenged as they learned their
797 more extended numerical lexicon.

798 Another way of interpreting the data observed would be to consider that VNS transcoding
799 development is more advanced that the one of FS. They would already retrieve the forms of 2-
800 digit numbers from LTM ($ADAPT^{ADV}$) while this would not yet be the case for FS children
801 ($ADAPT^{BASIC}$).

802 Finally, a very similar performance profile was observed in the analog-Arabic-transcoding
803 task, although the input and output codes were strictly similar for both populations. We
804 interpreted this finding by assuming that this task requires the activation of an intermediate verbal
805 representation of the number corresponding to the analog material; accordingly, this phenomenon
806 leads to a similar performance profile in both tasks.

807 To conclude, we provided evidence that the Vietnamese number-naming system's
808 transparency or more limited lexicon favors the acquisition of transcoding for children at the

809 beginning of first grade. French requires the mastery of a more extensive lexicon, which could
810 explain FS' higher lexical error-related position and class error rate.

811

Appendix A. Pilot studies.

The above tasks were evaluated in an initial pilot study to decide on the optimal test duration for the arithmetic task and the stimuli to use for the Analog-Arabic task. 42 Vietnamese first-graders (age range: 12 – 69 months, mean age of 6 years and 1 months, *SD* = 3.07 months, 23 boys) were recruited to participate in this pilot study. They were from a different school than those participated in the official testing. The testing was administered 1.5 months after they entered the elementary school class. Two Vietnamese (the first author and an experimenter) conducted the data collection through a collective testing. The student's teacher was present in the classroom to help manage order in the classroom. The first author gave the instructions, the other person distributed the task sheets to the children. At the end of the allotted time, the students had to stop writing and raise their hands (the teacher is the observer) to make sure that no student went over the allotted time. The answer sheets were then quickly collected to move on to the next task. The table 3 shows the results of this first pilot study.

For the Symbolic Magnitude Processing (SYMP Test) and number comparison, the time limit was 60 seconds.

For the arithmetic task, no time limit was given in this pilot study. Child were invited to raise hand when they had completed to answer the addition. The examiner collected the response sheet and recorded each student's response time. We found that the completion time ranged between 3 and 5 minutes.

For the Analog-Arabic-transcoding stimuli, we used bundles, as depicted in Fig. 6a, and observed that many of the children counted each stick in the bundle but did not understand that one stick bundle represented ten sticks. To differentiate between the children who understood this

and those who did not, we decided to remove the stick's trace on the top of the bundle and used stimuli, as shown in Fig. 6b.

Table 8

Results of pilot studies of numerical tasks

Tasks	*N*	*α*	Mean ± SD
Motor speed	42	-	39.28 ± 6.06
Number comparison	42	-	21.12 ± 3.26
Addition	42	.91	9.35 ± 3.92
Verbal-Arabic-transcoding	42	.91	19.00 ± 4.37
Analog-Arabic-transcoding	42	.98	12.88 ± 8.93
Analog-Arabic-transcoding	20	.92	12.50 ± 7.96

The new stimuli for the Analog-Arabic transcoding task were used in a second short pilot study testing 20 children. We observed that some participants understood that a bundle was ten sticks, while others failed to do so and either counted each stick on the bundle's front and, accordingly, falsely identified the bundle as containing four sticks or did not differentiate between the sticks and the bundles but considered the bundle as only one item. These new stimuli were selected for the official testing.



(a) Stick bundle in the first pilot b) Adjusted stimulus in the second pilot

Fig. 6. Stimuli used in the pilot and final testing process of the analog-Arabic-transcoding task.

844 **Appendix B. Comparison of the Vietnamese and French number systems.**

VBN	Vietnamese	Phonetic transcription	Syl	Syntax	French	Phonetic transcription	Syl	Syntax
2	hai	/haj^{1}/	1	–	deux	/dø/	1	–
5	năm	/năm^{1}/	1	–	cinq	/sɛ̃k/	1	–
8	tám	/tam^{5}/	1	–	huit	/wit/	1	–
11	mười một	/mɯɤj^{2} mot^{6}/	2	10 + 1	onze	/ɔ̃z/	2	–
12	mười hai	/mɯɤj^{2} haj^{1}/	2	10 + 2	douze	/duz/	2	–
13	mười ba	/mɯɤj^{2} ba^{1}/	2	10 + 3	treize	/tʁɛz/	2	–
14	mười bốn	/mɯɤj^{2} bon^{5}/	2	10 + 4	quatorze	/ka.tɔʁz/	3	–
15	mười lăm	/mɯɤj^{2} lăm^{1}/	2	10 + 5	quinze	/kɛ̃z/	2	–
16	mười sáu	/mɯɤj^{2} ʂaw^{5}/	2	10 + 6	seize	/sɛz/	2	–
10	mười	/mɯɤj^{2}/	1	–	dix	/dis/	1	–
20	hai mươi	/haj^{1} mɯɤj^{1}/	2	2 x 10	vingt	/vɛ̃/	1	–
30	ba mươi	/ba^{1} mɯɤj^{1}/	2	3 x 10	trente	/tʁɑ̃t/	2	–
21	hai mươi mốt	/haj^{1} mɯɤj^{1} mot^{5}/	3	2 x 10 + 1	vingt-et-un	/vɛ̃.t‿e œ̃/	3	20 + 1
24	hai mươi bốn	/haj^{1} mɯɤj^{1} bon^{5}/	3	2 x 10 + 4	vingt-quatre	/vɛ̃t.katʁ/	3	20 + 4
25	hai mươi lăm	/haj^{1} mɯɤj^{1} lăm^{1}/	3	2 x 10 + 5	vingt-cinq	/vɛ̃t.sɛ̃k/	2	20 + 5
26	hai mươi sáu	/haj^{1} mɯɤj^{1} ʂaw^{5}/	3	2 x 10 + 6	vingt-six	/vɛ̃t.sis/	2	20 + 6
31	ba mươi mốt	/ba^{1} mɯɤj^{1} mot^{5}/	3	3 x 10 + 1	trente-et-un	/tʁɑ̃.t‿e.œ̃/	3	30 + 1
32	ba mươi hai	/ ba^{1} mɯɤj^{1} haj^{1} /	3	3 x 10 + 2	trente-deux	/ /tʁɑ̃t.dø/	3	30 + 2
34	ba mươi bốn	/ba^{1} mɯɤj^{1} bon^{5}/	3	3 x 10 + 4	trente-quatre	/tʁɑ̃t.katʁ/	4	30 + 4
35	ba mươi lăm	/ba^{1} mɯɤj^{1} lăm^{1}/	3	3 x 10 + 5	trente-cinq	/tʁɑ̃t.sɛ̃k/	3	30 + 5
43	bốn mươi ba	/bon^{5} mɯɤj^{1} ba^{1}/	3	4 x 10 + 3	quarante-trois	/ka.ʁɑ̃t.tʁwa/	4	40 + 3
46	bốn mươi sáu	/bon^{5} mɯɤj^{1} ʂaw^{5}/	3	4 x 10 + 6	quarante-six	/ka.ʁɑ̃t.sis/	4	40 + 6

Note. VBN, verbal number; Syl, number of syllables. Vietnamese tones$^{1–6}$ based on the International Phonetic Alphabet Association.

Mean of Vietnamese (2.27 ± 0.77) vs. French syllables (2.32 ± 0.99). Paired-samples *t*-test showed no difference, $t(21) = -0.37$, $p = .715$.

845

Appendix C. Comparison of the rules required for number transcoding for Vietnamese and French based on the ADAPT^{BASIC} model.

	Vietnamese			French		
Structures	Rule	Condition	Action	Rule	Condition	Action
U	Pa	Input = unit Frame = no	Find PV in LTM Set PV in chain Stop	Pa	Input = unit Frame = no	Find PV in LTM Set PV in chain Stop
T	Pa	Input = unit Frame = no	Find PV in LTM Set PV in chain	Pd	Input = teen Frame = no	Find PV in LTM Add 1 in chain Set frame in chain
	Pc	Input = dix [ten] Frame = no	Set frame _ in chain			Step PV in empty slot Stop
	Pa'	Input = unit Frame = yes	Find PV in LTM Set PV in empty (_) Stop			
D	Pa	Input = unit Frame = no	Find PV in LTM Set PV in chain	Pb	Input = decade Frame = no	Find PV in LTM Set PV in chain Set frame _ in chain Read the next input
	Pc	Input = dix [ten] Frame = No	Set frame _ in chain	Pe'	Input = end Frame = yes	Fill empty slot with 0 Stop
	Pe'	Input = end Frame = yes	Fill empty slot with 0 Stop			
DU	Pa	Input = unit Frame = no	Find PV in LTM Set PV in chain	Pb	Input = decade Frame = no	Find PV in LTM Set PV in chain Set frame _ in chain Read the next input
	Pc	Input = dix [ten] Frame = No	Set frame _ in chain	Pa'	Input = unit Frame = yes	Find PV in LTM Set PV in (_)
	Pa'	Input = unit Frame = yes	Find PV in LTM Set PV in (_) Stop			Stop

Note. PV, primitive verbal.

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