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JEAN-MARC DEWAELE

Abstract

The present study investigates self-reported language choice for mental calculations among 1,454 adult multilinguals from a variety of linguistic, social and ethnic backgrounds. As mental calculation is a complex cognitive operation involving both language-dependent and language independent processes, we sought to establish a baseline of first language (L1) or foreign language(s) (LX) use for mental calculation and identify the factors that influence multilinguals' choice of language for mental calculation. A series of multiple regression analyses on calculation in the L1, L2, L3 and L4 showed that the following variables (in decreasing order) are the best predictors of language choice: frequency of general use, self-perceived proficiency in writing, socialization in the LX, context of acquisition, communicative and/or foreign language anxiety, perceived usefulness, and age of onset of acquisition. These variables explained over 40 percent of the variance in the foreign languages.

1. Introduction

Mental calculation is a complex cognitive operation that involves both verbal and non-verbal skills and—for those who remember their school days—it requires sustained effort to acquire this skill and sufficient concentration to perform it. Whether or not language really matters for monolinguals when doing mental calculation is a hotly debated point among specialists in numerical cognition (Noël, Robert & Brysbaert 1998). Recent research on the cognitive architecture of basic numerical skills in adult bilinguals suggests that memory for arithmetic facts is at least partially language-based (Campbell & Epp 2004). In order to perform mental calculation in both languages bilinguals need to possess number-fact representations in the two languages. Research has shown

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that these representations may differ in the two languages in terms of base, e.g., Western languages such as English versus Chinese, Japanese, or Korean (see Bialystok 2005; Pavlenko 2005). Multilinguals also need to be sufficiently proficient in their languages as number words need to be retrieved quickly, processed smoothly, and intermediate results need to be stored in working memory. A multilingual attempting to solve a mathematical problem in a second, third, fourth, or fifth language also needs a sufficient level of proficiency to understand the technical language in the instructions correctly. The multilingual also needs to know when a word is used mathematically and when not, and, finally, the multilingual needs to be proficient with the symbolic language of the domain (Mestre 1988). Bialystok (2005) underlines that "bilingualism does not alter children's ability to construct the necessary mental representations for mathematics relative to monolinguals, but (...) problems framed in a verbal context that exceeds their linguistic sophistication imposes a barrier to accessing those representations and interferes with performance" (2005: 421).

The existing research on multilingualism and mathematics covers a wide area: from education-based studies on code-switching practice in bilingual classrooms (Moschkovich 2002, 2007), the relationship between multilingualism research and research concerned more generally with language and communication in mathematics education (Morgan 2007), to numerical cognition research (Campbell & Epp 2004, 2005), to psycholinguistic research investigating the effect of independent variables such as the influence of a language's number name word-lengths on the ease of mental calculation in that language (Ellis 1992); on variation in digit span (Chincotta & Underwood 1997) and on language switching cost (Campbell 2005; Meuter & Allport 1999).

Some of the important studies on simple[2] and complex mental calculation among bilinguals will be reviewed in the following section.

2. Previous research on bilingualism and numerical cognition

Although the focus of the present study is on language choice for mental calculation, we will present a short overview of research into bilingual performance in simple mental arithmetic and more complex numerical operations. Indeed, it has been argued that a crucial distinction has to be made between simple arithmetic facts and complex mental calculation for differences in the working memory/phonological loop involvement in simple fact retrieval versus complex calculation (see, e.g., Bernardo 2001; De Rammelaere et al. 2001; De Rammelaere & Vandierendonck 2001; Logie et al. 1994; Rusconi, Galfano & Job in press).

Cognitive models of mental arithmetic assume that for the calculation of single digits, educated adults generally retrieve solutions from stored knowledge representations, i.e., arithmetic facts (Campbell & Epp 2005).[3]

Rusconi, Galfano & Job (in press), in their review of recent studies in the field, reported that neuropsychological research suggests that arithmetic facts are likely stored separately from either other semantic knowledge or other numerical skills. However, despite this neuropsychological dissociation between language-related abilities and arithmetic facts retrieval, the authors point to behavioral and electrophysiological evidence showing that similar mechanisms may govern both arithmetic lexicon and word lexicon (Rusconi, Galfano & Job in press).

2.1. *Research on simple mental arithmetic*

The seminal study by Marsh and Maki (1976) found that 20 adult bilingual college students solved simple arithmetic problems more rapidly in their preferred language (i.e., the language in which they originally learned arithmetic) than in their non-preferred language. There was small difference between performance in a preferred language and a non-preferred language (0.2 seconds). Performance (in English) showed a limited but statistically significant difference of about 0.49 seconds for mean response time between monolinguals and bilinguals who preferred English to Spanish. Monolinguals and bilinguals had similar error rates.

Mägiste (1980) compared arithmetical performance of monolinguals and bilinguals and it showed that bilinguals needed more time to perform the tasks and made more errors than the monolinguals. This study has been strongly criticized however. For Moschkovich (2007) the conclusions of the Mägiste (1980) study are exaggerated since few of the differences reached statistical significance.

McClain and Shih Huang (1982) confirmed and extended the findings of Marsh and Maki (1976). McClain and Shih Huang compared response times in the preferred and non-preferred languages for Chinese and Spanish bilinguals. Participants had to solve simple addition problems auditorily presented in either their preferred or non-preferred language. The answer had to be given in the language in which the problem was presented. Solution time was found to be 0.227 seconds faster in the preferred language. Performance and error rates for monolinguals and bilinguals using their preferred language did not differ significantly. The authors attribute the preferred language advantage to faster encoding and/or response times in the preferred language. They also found that by allowing bilinguals to choose the language, solution time decreased. However, a forced change from one language to another within an experimental session was linked to increased solution times. In other words, the preferred language advantage disappeared when bilinguals were required to use only one of their languages during an experimental session.

Meuter & Allport (1999) investigated the cost of language switching and selection among bilinguals naming numerals in either their L1 or L2. They found greater RT (response time) costs for bilinguals to switch to their L1 from their L2 relative to switching to L2 from L1. The authors link this "paradoxical" asymmetry in the cost of switching languages to differences in relative strength of the two languages and the involuntary persistence of the previous language set across an intended switch of language. Naming in the weaker L2 requires a stronger inhibition of the dominant L1 and the effort needed to overcome this inhibition into the following (switch) trial results in "negative priming" of the L1 lexicon as a whole (Meuter & Allport 1999).

Campbell (2005) investigated asymmetrical language switching costs in digit naming and simple arithmetic by Chinese–English bilinguals. These language switching costs were found to vary with stimulus format (Arabic or Mandarin numerals), and the asymmetry appeared both with direct retrieval (e.g., naming the digit "8") and indirect retrieval from the lexicon (e.g., answering "2 + 6").

Noël and Fias (1998) concluded that there is a clear advantage in calculation speed for the preferred language and argue that encoding and production processes as well as the possible influence of working memory (which may vary according to the participant's language), rather than access to arithmetic facts, are the main causes for this phenomenon.

Vaid and Menon (2000) and Spelke and Tsivkin (2001a) pointed out that the preferred language for mental calculation is not necessarily the L1 but the language of instruction. Dehaene (1997) suggested that bilinguals who moved to a different linguistic community and whose L1 is in the process of attrition continue to calculate in that L1. However, there is some evidence that language preference or dominance for cognitive operations can shift. Tamamaki's (1993) analysis of language preference for arithmetic operations among Japanese-English bilinguals residing in the US showed that the L1 dominance decreases with the length of residence in the L2 context. Similar patterns emerged in Bernardo's (2001) study of Filipino–English bilinguals who preferred to process numbers in English, having had more extensive experience with this task using the English verbal code, despite the fact that English was their L2 (2001: 974).

Spelke and Tsivkin (2001b) focused specifically on the question of language-in/dependence for numerical cognition. They point out, first of all, that there is the possibility that numbers and arithmetic facts are represented in the specific natural language in which they are learned (2001b:

47). As a consequence, problems presented in a different language need to be either translated to the language of learning or their solutions must be calculated anew. This translation process or the less well-established fact-learning in the L2 would account for the longer response times and lower accuracy with retrieving arithmetic facts in a L2 (p. 47). Spelke and Tsivkin's second interpretation is that numbers and arithmetic facts are represented in a language-independent manner. In order to access those representations, however, the bilingual must "transform a spoken problem into a representation in the system in which the answer is computed, and then transform the result of the computation back into the spoken language for production. These decoding and encoding processes might proceed automatically, even when no spoken response is required, producing the language-specific effects described above" (2001b: 47).

In an attempt to shed light on the issue of language-in/dependence of number facts, Spelke and Tsivkin (2001b) designed an ingenious experiment. Their participants were eight Russian-English bilingual college students from Ithaca who had come to the US after puberty and had attained high levels of proficiency in English while remaining fluent in Russian. They were taught new numerical operations, new arithmetic equations, and new geographical or historical facts involving numerical or non-numerical information. After learning a set of items in Russian and English, participants were tested for knowledge of those items, and new items, in both languages. In all the studies, subjects were found to retrieve information about exact numbers more effectively in the language of training, and they solved trained problems more effectively than untrained problems (2001: 45). In contrast, the bilinguals retrieved information about approximate numbers and non-numerical facts with equal efficiency in Russian and English, and their training on approximate number facts generalized to new facts of the same type. The authors conclude that "small, exact numbers and large, approximate numbers can be represented independently of language, and that only representations of exact large numerosities depend on a specific language with a counting system" (2001: 83). Language thus "appears to play a role in learning about exact numbers in a variety of contexts, a finding with implications for practice in bilingual education" (2001: 45).

Rusconi and her colleagues tried a different methodological approach to investigate the representation of arithmetically related verbal numerals in the L1 and L2 of bilingual speakers (Rusconi et al. in press). They used indirect tasks (i.e., tasks that do not require arithmetic knowledge, such as number-matching). These indirect tasks are much less sensitive to working memory manipulations. Bilinguals had to decide whether a target word (e.g., forty-two) was present or not in the previous display where two cue words had been shown (e.g., six and seven). The results suggest that bilinguals possess multiple arithmeticons, at least for the easiest facts (Rusconi et al. in press).

2.2. *Research on complex numerical cognitive operations*

The two following studies, Cohen (1994) and Centeno-Cortés and Jiménez Jiménez (2004) looked at complex numerical cognitive operations in L2 learners.

Cohen (1994: 188) investigated the issue of language preference in math in a sample of 32 Anglo-American pupils in a Spanish full immersion school in the US. The research focused on preferences with regard to the use of Spanish for communication and for solving verbal and numerical problems in math. Data were collected through self-reports and observation of introspective and retrospective verbal reports. The results show that although participants started the mathematical problems in Spanish, they switched to the L1 for an on-line translation before solving it, or they continued in Spanish until they encountered a conceptual problem. The author observes that the results from his study "seem to lend some support to the popular belief that people think in their native language when they do maths, regardless of the language they are speaking at the time." Cohen (1994: 192) concludes that even after six or seven years of immersion schooling his participants might have been behaving externally and socially in Spanish, but not psychologically or cognitively: "The development of this other self, who can and does perform cognitive operations in the target language, may prove to be the exception rather than the rule, but more extensive research will be necessary to determine this."

A recent sociocultural study by Centeno-Cortés and Jiménez Jiménez (2004: 31) on mathematical problem-solving in the L2 revealed similar patterns to the ones uncovered by Cohen (1994). Participants were six American students of Spanish from an intermediate conversation class and six American advanced speakers of Spanish as a second language (L1 English) who were instructors of Spanish. The authors considered private verbal thinking, defined as a particular type of private speech "characterized as being the externalization of the process of reasoning during a problem-solving activity." Intermediate learners used the L2 mainly while reading and for repetitions of parts of the questions, while advanced L2 speakers extended its use to the actual thinking process (during the reasoning stage). They read the questions aloud in Spanish and sometimes tried to carry out their thinking in Spanish: "However, most of them could not sustain the L2 throughout the reasoning process and had to switch into English" (Centeno-Cortés and Jiménez Jiménez

2004: 23). Some advanced L2 users incorporated Spanish elements into the English thinking process. Those who maintained the entire process in Spanish either came up with an incorrect response or gave up. The authors conclude that a higher language proficiency level provides the L2 user with an extra set of cognitive strategies in the L2 that can be employed in order to solve a challenging problem in the L2. They do not suggest that this new set overrides the strategies already developed in the L1 as their advanced L2 users shifted back to their L1 when the problem became too difficult. However, they do not "exclude the idea that a complete change in an individual's cognitive system from L1 to L2 is possible" (Centeno-Cortés and Jiménez Jiménez 2004: 31–32).

This short overview of some studies on numerical cognition and bilingualism cannot do justice to the richness and the diversity of the field. It merely gives an idea of the issues raised by researchers investigating the complex relationship between language(s) and numerical cognition. The bulk of the work on bilingualism and mathematical cognition is situated in the field of cognitive arithmetic, and more specifically studies focusing on simple arithmetic. Using complex experimental designs, researchers try to uncover how number facts are represented and processed among bilinguals. Research on complex numerical cognitive operations performed by L2 learners in immersion education suggests that the cognitive process may be hampered in the weaker language.

The dominant epistemological stance in numerical cognition and bilingualism is the etic perspective (i.e., a description of a behavior according to the researcher's point of view) (Pike 1967). In other words, participants produce data that are analyzed in a clinical way by the researcher. The self-assessment or the opinion of the participant is irrelevant in this etic perspective. We do not question the value of such an etic approach but we will argue that an emic perspective (i.e., a description of behavior in terms meaningful—consciously or unconsciously—to the participant) can provide new information to researchers in the field of bilingualism and numerical cognition.

3. Aims and outline

The aim of the present cross-sectional study is not to measure speed or accuracy of computation in a multilingual context, nor to compare the performance of monolinguals with that of multilinguals, but rather to determine usual language preference for mental calculation among adult multilinguals. Before clarifying the complex cognitive issues, it is important to establish a baseline of L1/LX use for mental calculation in multilinguals and to determine what factors influence multilinguals' choice of language for mental calculation. We are particularly interested in a possible shift in preference from the L1 to an LX (any language learned later in life) for mental calculation. In other words, we will consider individual differences in self-reported language choice for mental calculation in a socially and ethnically diverse group of adult multilinguals with different native languages who have been using one or several LXs for quite some time since leaving school without necessarily reaching native-like proficiency in them (cf. Cook 2002).

Following the research questions, we present the methodology: a description of the sample, the research design, and a brief contextualization of the independent and dependent variables followed by their operationalization in the present study. We formulate the hypotheses in the following section. Next, we will present the quantitative analyses and a few spontaneous observations by participants on mental calculation. Finally, we will consider what the findings add to the existing body of knowledge on bilingualism and numerical cognition.

4. Research questions

The present contribution addresses the following research questions:

1) Is the L1 the preferred language for mental calculation for all multilinguals?
2) What social, psychological and attitudinal variables, i.e., frequency of general use of a language, degree of socialization, context of acquisition, age of onset of learning, self-perceived proficiency in writing, communicative anxiety, and perception of usefulness, are linked to language choice for mental calculation among multilinguals?

5. Method

The data have been gathered through an on-line web questionnaire with open-ended and closed-ended questions aimed at multilinguals (Dewaele & Pavlenko 2001). The questionnaire contained 35 questions concerning emotional and non-emotional language use in different situations in up to five languages. It included questions on social, demographic and linguistic background and questions on the relationship between languages and emotions. The closed questions allowed the gathering of numerical data through the use of Likert scales and permitted further statistical analysis. A number of open-ended questions at the end of the questionnaire invited participants to comment on their linguistic experiences.

5.1. *Participants*

A total of 1,454 multilinguals (1,033 females, 421 males) contributed to the web questionnaire database used in the present study. The participants spoke a total of 77 different L1s. Anglophone native speakers represent the largest group (n = 433), followed by native speakers of Spanish (n = 162), French (n = 159), German (n = 131), Dutch (n = 96), Italian (n = 66), Finnish (n = 38), Catalan (n = 36), Russian (n = 35), Portuguese (n = 34), Swedish (n = 24), Greek (n = 21), Chinese (n = 18), Afrikaans (n = 14), Danish (n = 14), Japanese (n = 14), Welsh (n = 11), and Polish (n = 10). The remaining 138 participants share another 57 languages.

The most frequent L2 is English (n = 607), followed by French (n = 303), Spanish (n = 143) and German (n = 96). French is the most frequent L3 (n = 322), followed by English (n = 318), German (n = 190) and Spanish (n = 123). The same languages are the most frequent L4s: German (n = 192), French (n = 160) and Spanish (n = 124). The most frequent L5s are Spanish (n = 81), German (n = 66) and Italian (n = 63).

The mean age of onset of learning was 8.5 yrs (SD = 6.4) for the L2; 13.7 yrs (SD = 6.7) for the L3; 17.8 yrs (SD = 6.9) for the L4 and 21.6 yrs (SD = 7.9) for the L5. The L2 was defined as the second language to have been acquired, the L3 the third, etc.

Participants are generally highly educated with 155 having a high school diploma, 418 a Bachelor's degree, 452 a Master's degree, and 424 a doctoral degree. Age ranged from 16 to 73 (Mean = 35.5; SD: 11.2).

One could argue that the format of the questionnaire gives inordinate importance to the order of acquisition. While I fully agree that multilinguals' multicompetence (Cook 2002) is dynamic in nature, I showed in Dewaele (2005a) that the order of acquisition is a very powerful predictor of language choice. In other words, the labels L1, L2, L3, L4, and L5 are not just arbitrary constructions to be used for convenience's sake. They do seem to have a psycholinguistic validity. The web questionnaire was in English, which obviously restricted access to multilinguals with a sufficient understanding of that language. It is unlikely that the fact that English had to be used affected the results. The questionnaire merely invited participants to report their linguistic experiences; it did not seek to test them in any way. The use of an open web questionnaire does raise the question of participant self-selection. As Buchanan (2001) noted, self-selected participants who are motivated enough to complete an on-line questionnaire are likely to differ from a "random sample" of internet users (Buchanan 2001: 2–3). Inevitably, "on the internet, standardization of and control over the testing situation is lost" (Buchanan et al. 2005: 115). The resulting over-representation of highly educated, female, polyglot participants renders the sample unrepresentative of the general population. One possible reason for this is that the questionnaire required a certain degree of self-confidence, an interest in the topic, and a sufficient amount of metalinguistic awareness of one's language practices. We discarded the data of about 200 participants who did not complete the questionnaire. On the whole, we feel that the potential benefits of the design, namely the possibility to collect data from adult multilinguals with a wide variety of language combinations, outweigh the disadvantages. It needs to be kept in mind however when interpreting the findings that our participants constitute an "elite" self-selected sample of polyglots.

5.2. *Research design*

In addition to gender and education level, seven main independent variables were selected in the present design: 1) frequency of general use of a language, 2) degree of socialization in the LX (i.e. any language other than L1), 3) acquisition context, 4) age of onset of language learning, 5) self-perceived written proficiency, 6) communicative anxiety, and 7) perceived usefulness of a language.

The effects of the independent variables on frequency of language choice for mental calculation will be calculated separately for every language (L1, L2, L3, L4, L5). Every analysis will start with a correlation analysis and will be followed by a standard multiple regression analysis. This procedure will allow us to obtain a clear picture of the amount of variance predicted by the independent variables for every language. Three participants mentioned mental calculation in their answers to the open questions. Their observations will be used as an illustration of the trends uncovered in the quantitative data.

5.3. *Independent variables*

5.3.1. *General frequency of use of a language.* The general frequency of use of a language has been found to be a strong predictor of perception of the emotional force of swear words in a target language (TL), of frequency of swearing in a TL and of expression of emotions in a TL (Dewaele 2004a, 2004b, 2005b, 2006). The adage "practice makes perfect" certainly applies to multiple language use. Frequent use of a

Table 1. *Distribution of participants according to frequency of language choice for general use*

Frequency	*L1*		*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%	N	%
Never	2	0.1	31	2.1	118	9.8	150	17.5	99	21
Yearly	11	0.8	125	8.7	314	26.1	286	33.4	149	31.6
Monthly	51	3.5	126	8.7	198	16.5	139	16.2	82	17.4
Weekly	169	11.7	233	16.1	239	19.9	129	15.1	69	14.6
Daily	284	19.7	349	24.4	171	14.2	75	8.8	43	9.1
All day	928	64.2	581	40.2	163	13.5	78	9.1	30	6.4
TOTAL	1445	100	1445	100	1203	100	857	100	472	100

language has been shown in previous research to be linked to development of grammatical accuracy as well as the more elusive aspects of sociopragmatic, sociolinguistic and sociocultural competence (Dewaele 2004d). Information about the general use of a language has been collected through the following question: How frequently do you use each of the languages? Possible answers on a 5-point Likert scale included: 0) never, 1) yearly, 2) monthly, 3) weekly, 4) daily, 5) all day. Sample sizes may vary across the analyses because some participants did not provide data for all the variables (see table 1).

5.3.2. *Socialization in the LX.* Research into language socialization in multilingual settings shows that the process of acquisition of new interpretative frameworks occurs throughout the lifetime of multilingual speakers (Bayley & Schecter 2003). Pavlenko (2004) showed that second language socialization affects language choice for the expression of anger and (other) feelings in parent-child communication within multilingual families. While a majority of multilingual parents reported a preference for the L1 for emotional communication with their children, a minority of parents reported that as result of the socialization process their LX had acquired strong affective connotations and had become their preferred language for the communication of emotions with their children.

The variable "socialization in the LX" was defined following the procedure set out in Dewaele (2006). It is a derived variable based on the difference in the general frequency of use of the L1 and an LX (the L2, L3, L4 or L5). The subtraction of the score for the L1 and the score for the LX gives a value that reflects the difference in frequency of use of the L1 and the LX. For example, if a participant indicated that s/he used the L1 all day (score 5) and the L2 weekly (score 3), the L2 socialization score would be 2, indicating a very weak degree of socialization in the L2. If,

Table 2. *Distribution of participants according to degree of socialization in the LX*

LX Socialization	*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%
Very weak	745	51.2	965	78.5	743	85.4	451	88.3
Weak	376	25.9	123	10	70	8.0	37	7.2
Moderate	176	12.1	83	6.7	38	4.4	13	2.5
Strong	157	1.8	59	4.8	19	2.2	10	2.0
TOTAL	1454	100	1230	100	870	100	511	100

on the other hand, the L2 was used all day (score 5) and the L1 only weekly (score 3), the L2 socialization score would be −2, indicating a moderate degree of socialization in the L2. The distribution across categories can be seen in Table 2. The category very weak socialization represents over half the participants in the L2 and it rises to three quarters of the participants for the L3, and an even higher proportion for the L4 and L5. Inversely, those in the categories moderate to strong socialization represent about a fifth of the participants in the L2 and this drops to 10% and less in the subsequent languages.

5.3.3. *Context of acquisition.* Context of acquisition emerged as a significant variable in a number of previous studies on emotion and bilingualism (Dewaele 2004a, 2004b, 2005b). The effect of context of acquisition was found to have a significant effect on the self-reported use and perceived emotional force of swear words and taboo words in up to five languages among 1,039 multilinguals from the earlier version of the same corpus. The effect of context of acquisition was generally stronger for self-reported language choice for use of swearwords than for perception of their emotional force. Participants who learned their language(s) through classroom instruction only were less likely to use swear words and taboo words in that language and they rated them as being less forceful compared to the rating of a naturalistic—or mixed—context learners. The effect of authentic language use with native speakers of the TL on the development of the interlanguage has been clearly demonstrated in a study by Housen (2002). He looked at the English L2 of Italian primary school children in four different European schools. The amount of formal instruction was similar across the groups; only the amount of extra-curricular contact with the TL varied. The group who had regular contact with English outside the classroom scored significantly higher on a range of morphological and lexical measures. Similar patterns have also emerged from numerous studies on the acquisition of sociolinguistic

Table 3. *Distribution of participants according to context of acquisition of the LX*

Context of acquisition	*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%
Instructed	560	39.1	811	67.1	596	69.1	316	66.4
Mixed	653	45.6	322	26.7	186	21.6	100	21.0
Naturalistic	219	15.3	75	6.2	81	9.4	60	12.6
TOTAL	1432	100	1208	100	863	100	476	100

competence (for an overview, see Dewaele 2004d). The studies showed that after their stay abroad or after prolonged contact with native speakers the L2 users approximated roughly—though not exactly—to the native speaker norm on a range of sociolinguistic variables. It seems thus that living abroad for an extended period does something unique to the learners' usage which classroom input does not.

In the present study three types of contexts of acquisition were considered and ordered according to the amount of extra-curricular contact with the target language: 1) instructed context (i.e., formal classroom contact only); 2) mixed context (i.e., classroom contact + naturalistic contact), and 3) naturalistic context (i.e., no classroom contact, only naturalistic communication outside school). No further distinction was made between types of formal instruction, such as, for instance, "immersion classrooms," where the TL serves as the medium for teaching non-language subject matter and "non-immersion classrooms," where the TL is the instructional target. Similarly, the notion of "naturalistic context" as used here is a cover term for a wide range of ways in which a language can be learned without guidance from a particular teacher or program, but developed gradually or spontaneously through interaction with speakers of the TL.

Table 3 presents the distribution of the participants according to context of acquisition for the L2, L3, L4 and L5. The most striking difference occurs between the L2 and the other languages: the L2 was learned solely through formal instruction in less than 40% of the cases, while this rose to more than 65% of the cases for the L3, L4 and L5.

5.3.4. *Age of onset of learning an LX (AoA).* One of the big debates in Second Language Acquisition concerns the optimal age to start learning a foreign language. The problem is that there is lot of contradictory evidence on the effect of AoA (for excellent overviews see Birdsong 2005; DeKeyser and Larson-Hall 2005). First, a number of recent studies that looked at AoA in formal instruction of English found that older beginners significantly outperformed younger ones in both oral and written proficiency when the number of hours of instruction was held constant. Additionally, several studies have shown that younger starters have an advantage over older starters in the area of phonology. The third position is that younger starters might be better in the long run. Our own studies on language choice for emotional speech among adult multilinguals have exactly the type of time-scale that Singleton and Ryan (2005) were pleading for (i.e., several decennia). AoA was found to predict perception of emotional force of swear words in the L2 (but not in the L3, L4 and L5), it had no significant effect on language choice for swearing (Dewaele 2004a, 2004b). A stronger effect of AoA was found in Dewaele (2006) for the language choice for the expression of anger (based on the complete corpus with the 1,454 multilinguals). Participants who had started to learn a language early were more likely to use that language to express anger later in life. We argued that the long time-span between the acquisition phase and the moment the data were gathered (an average of 20 years) could account for the relative weakness of the effect of AoA. A prolonged period of use or non-use of a language may have reinforced or annulled the effect of AoA on language choice. Some participants reported never having used a language again after a certain age; others reported picking it up again much later and becoming highly proficient in the language. It is therefore possible that the effect of some more recent life-events can overwhelm the effect of variables linked to the genesis of the language learning experience, but that these remain detectable like a kind of background radiation.

As the statistical technique in the present study is standard multiple regression analysis rather than multivariate analysis, we decided not to group participants in a limited number of AoA categories—which would have entailed a loss of detail—but rather maintain the full range of values. Since the AoA range for the different languages spanned from birth to the age of 56, the resulting table would have displayed 280 cases (5×56). To avoid such a massive table, we opted for a graphic representation of the distribution of participants with AoA ranging from birth to age 30 (see figure 1). The last value reflects the sum of individuals who started a learning an age after the age of 30. Three cohorts of participants stand out for AoA of the L2: more than 15% acquired the L2 from birth, 11.5% acquired it at the age of 10, and another 12% acquired it from age 11. The remaining AoA groups represent fewer than 10% of the total number of participants. The "peak" for AoA for the L3 comes at age 12 with 14.5% of the participants. These peaks grow smaller and move up for the L4 (age 14 with 9.3% of the participants) and the L5 (age 18 with 1.3% of the participants).

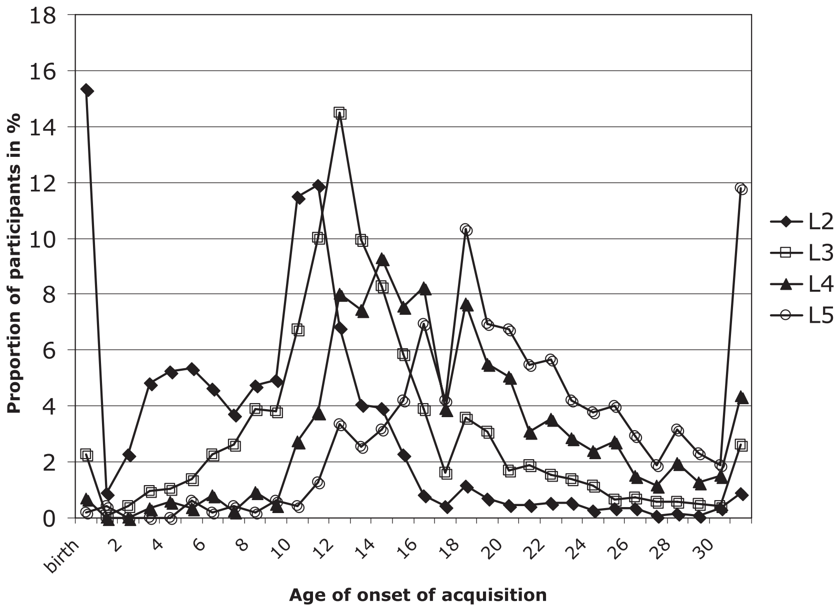

Figure 1. *Distribution of participants according to age of onset of learning the LX*

5.3.5. *Self-perceived competence.* Self-perceived competence is a person's evaluation of their ability to communicate (McCroskey & McCroskey 1988). This is the kind of holistic statement that is expected in the curriculum vitae under the heading "language knowledge." It is a judgment that we are all forced to make at some point. It probably reflects a sum of various aspects of the L2 including perceived competence in grammar, phonology, lexis, syntax, pragmatics and it is probably also influenced by past failures or successes in the L2, as well as recent experiences in intercultural communication. Self-perceived competence is considered by MacIntyre (1994) to be one of the two antecedents underlying Willingness to Communicate. Donovan and MacIntyre (2004) found a negative correlation between self-perceived competence and communication apprehension. In other words, higher levels of self-perceived competence are linked to lower levels of communication apprehension. Self-perceived competence in writing was measured through 5-point Likert scales: On a scale from 1 (least proficient) to 5 (fully fluent) how do you rate yourself in writing? Possible answers included: Minimal, Low, Medium, High, Maximal. Table 4 shows that while more than 96% of participants judge themselves to be highly to maximally fluent in writing in their L1, only three quarters rate themselves as highly for the L2, and

Table 4. *Distribution of participants according to self-perceived proficiency in writing*

Proficiency	*L1*		*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%	N	%
Minimal	20	1.4	52	3.6	165	11.3	228	26.5	170	36.1
Low	7	0.5	77	5.3	237	16.3	212	24.7	122	25.9
Medium	19	1.3	208	14.3	334	23	220	25.6	94	2.0
High	92	6.3	430	29.6	322	22.1	142	16.5	61	13.0
Maximal	1311	9.2	677	46.6	162	11.1	58	6.7	24	5.1
Total	1449	100	1444	100	1220	100	860	100	471	100

Table 5. *Distribution of participants according to self-perceived usefulness*

Usefulness	*L1*		*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%	N	%
Not at all	9	0.6	9	0.6	27	2.3	44	5.5	27	6.3
Somewhat	41	2.8	54	3.8	135	11.5	153	19.0	74	17.3
More or less	89	6.2	76	5.3	183	15.7	151	18.8	85	19.9
To a large extent	181	12.6	221	15.4	268	22.9	182	22.6	96	22.5
Absolutely	1122	77.8	1074	74.9	556	47.6	275	34.2	145	34.0
Total	1442	100	1434	100	1169	100	805	100	427	100

the proportion drops to a third for the L3, a quarter for the L4 and less than a fifth for the L5.

5.3.6. *Usefulness.* Attitudes toward languages have been shown to strongly affect their acquisition and use (Dörnyei 2003a). The attitude toward a language is determined by a complex interaction of societal, historical, and individual variables. A positive attitude towards a language is usually linked to higher proficiency in that language (Dewaele 2005c). We focused on perceived emotionality and usefulness of languages in the questionnaire. A preliminary analysis showed that perceived emotionality was not linked to our dependent variable, hence the decision to focus solely on perceived usefulness. A language judged useful by a participant would imply a constant investment on the part of that individual to maintain or develop that language to a satisfactory level. The question was formulated as follows: Here are some subjective statements about the languages you know. Please mark to what extent they correspond to your own perceptions. There are no right/wrong answers. How useful is your L1/L2/L3/L4/L5? Participants had the option between not at all, somewhat, more or less, to a large extent, absolutely. Table 5 shows that three quarters of the participants judge their L1 and L2 to be absolutely useful. This decreases to about half for the L3 and a third of participants for the L4 and L5.

5.3.7. *Communicative and/or foreign language anxiety.* MacIntyre and Gardner (1994) proposed a 3-stage model of foreign language anxiety—which is a particular manifestation of communicative anxiety. First, foreign language students can experience fear at the input stage when they are presented with new information in the foreign language. Next, anxiety at the processing stage can debilitate cognitive operations performed on external stimuli and memory processes. The students may experience a reduced ability to understand messages and learn new vocabulary. Finally, anxiety at the output stage can interfere with the retrieval of previously learned material and might hinder the students' ability to produce the foreign language (MacIntyre & Gardner 1994: 301). The authors also found that communicative anxiety "tends to correlate with measures of performance in the second language but not in the native language" and concluded that the "potential effects of language anxiety on cognitive processing in the second language may be pervasive and may be quite subtle." We can thus hypothesize that foreign language anxiety might hamper processing during mental calculation in a foreign language.

The questionnaire (Dewaele & Pavlenko 2001) contained one closed question, based on a 5-point Likert scale, formulated as follows: How anxious are you when speaking your different languages with friends? (Circle appropriate number, 1 = not at all, 2 = a little, 3 = quite anxious, 4 = very anxious, 5 = extremely anxious). Table 6 shows that more than 90% of participants is not at all anxious in the L1, this proportion drops to less than three quarters for the L2, drops below half for the L3 and hovers around a third of participants for the L4 and L5.

Table 6. *Distribution of participants according to communicative or foreign language anxiety*

Anxiety	*L1*		*L2*		*L3*		*L4*		*L5*	
	N	%	N	%	N	%	N	%	N	%
Not at all anxious	1282	90.8	951	69.2	445	43.9	209	33.6	102	31.4
A little anxious	96	6.8	331	24.1	328	32.4	235	37.8	121	37.2
Quite anxious	16	1.1	68	4.9	144	14.2	94	15.1	54	16.6
Very anxious	8	0.6	13	0.9	57	5.6	49	7.9	21	6.5
Extremely anxious	10	0.7	11	0.8	39	3.8	35	5.6	27	8.3
Total	1412	100	1374	100	1013	100	622	100	325	100

5.4. *Dependent variable*

Self-reported frequency of language choice for mental calculation is the dependent variable in the present study. Data were obtained through the following question: If you perform mental calculation, what language do you typically use? Answers were elicited on a 5-point Likert scale (never = 1, rarely = 2, sometimes = 3, frequently = 4, all the time = 5). Information was collected for the L1, L2, L3, L4, and L5. The dependent variables are thus the numerical values reflecting frequency of habitual language choice for mental calculation. A series of one-sample Kolmogorov-Smirnov tests revealed that the values for frequency of language choice for mental calculation in the five languages are not normally distributed (Kolmogorov-Smirnov Z values vary between 6.2 and 14.2, all $p < .0001$). The distribution of participants across 5 frequency categories (ranging from "never use this language" to "use this language all the time" for mental calculation) are skewed towards the high end of the continuum for the L1, and are skewed towards the low end of the continuum for the L3, L4 and L5 (see table 7). As a consequence, Spearman Rank tests were used as nonparametric equivalents to Pearson's r tests, and Mann-Whitney tests were used instead of t-tests. A series of standard multiple regression analyses were performed to examine the hypothesized relationships between the variables and to determine the amount of unique variance predicted by every single independent variable. According to Tabachnick and Fidell (2001) the sample size should be sufficient for this type of analysis, the rule of thumb being: $N = 50 + 8*M$ (M being the number of explanatory variables). Our analyses include 4 exploratory variables for the L1 and 7 explanatory variables for the L2, L3, L4 and L5. Our minimal sample size should therefore be 82 for the L1 and 106 for the other languages. That assumption is met for all languages. Since the data are not normally distributed, we performed a number of supplementary analyses to determine whether the major assumptions

Table 7. *Distribution of participants according to frequency of language choice for mental calculation*

Mental calculation	*L1*		*L2*		*L3*		*L4*		*L5*	
	n	%	n	%	n	%	n	%	n	%
Never	44	3.0	304	22.3	573	54.1	527	71.9	310	77.1
Rarely	39	2.7	219	16.1	224	21.1	108	14.7	54	13.4
Sometimes	72	5.0	323	23.7	164	15.5	57	7.8	22	5.5
Frequently	342	23.7	333	24.5	75	7.1	34	4.6	14	3.5
All the time	948	65.6	182	13.4	24	2.3	7	1.0	2	0.5
TOTAL	1445	100	1361	100	1060	100	733	100	402	100

for multiple regression had been violated. Correlation analyses showed values that were neither too high nor too low (Tabachnik & Fidell 2001) suggesting that multicollinearity is not a problem. Collinearity diagnostics showed that tolerance values (1 – R2) were well above zero and that this assumption has therefore not been violated. Residual scatterplots and normal probability plots showed no major deviations from normality, although it came close for the data of the L1.

6. Hypotheses

Considering the findings reported in the literature, it was hypothesized:

1) That the speakers' L1 would be the preferred language for mental calculation and that there would be a monotonic decline for languages learned subsequently;
2) That frequent users of a language would be more likely to use that language for mental calculation.
3) That multilinguals with higher levels of socialization (defined as a comparatively higher frequency of use of the LX compared to the L1) in an LX would prefer that language for mental calculation;
4) That participants who learned their LX in an instructed setting (i.e., exclusively through the foreign language class) would use it less frequently for mental calculation than participants who learned the LX in a mixed or naturalistic environment (for example in immersion education where math could be taught in the target language);
5) That participants who started learning an LX at a younger age would use it more frequently for mental calculation than participants who started learning the LX later;
6) That participants who feel more proficient in a language would also use it more frequently for mental calculation than participants who feel less proficient;
7) That participants experiencing higher levels of communicative or foreign language anxiety in a language would be less likely to use that language for mental calculation.
8) That participants who perceive a language to be useful would be more likely to use that language for mental calculation.

7. Results

7.1. *Preferred language for mental calculation*

An analysis of the mean scores of frequency of language choice for mental calculation shows that multilinguals use the L1, on average,

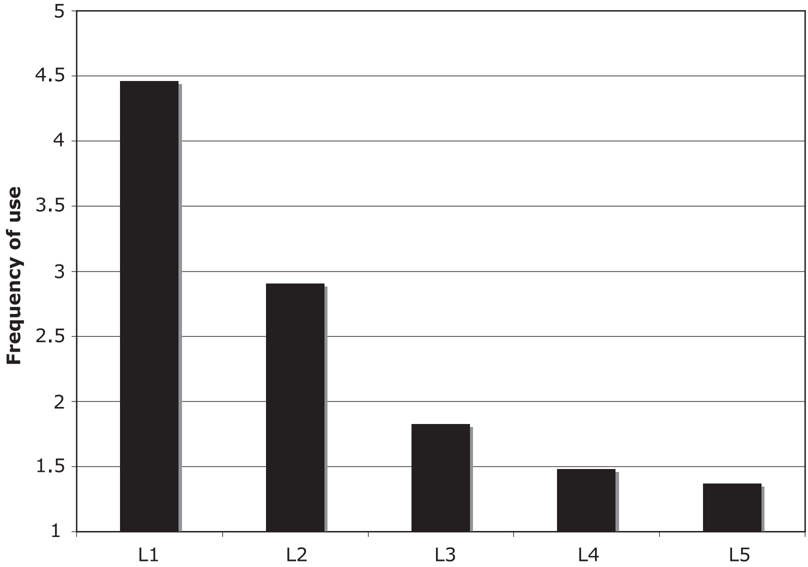

Figure 2. *Average frequency of language choice for mental calculation*

between frequently and all the time to do mental calculation (mean score: 4.46, SD = .93). The L2 is used, on average, sometimes (mean score: 2.91, SD = 1.35). This drops to rarely for the L3 (mean score: 1.82, SD = 1.07). The L4 and L5 are, on average, rarely or never used: mean score: 1.48, SD = .89 and mean score: 1.37, SD = .78 respectively (see figure 2). This means that while the analysis of the data for the L4 and the L5 is statistically possible, it involves a restricted data range.

Wilcoxon Signed Ranks Tests confirm that the frequency of use of a language for mental calculation decreases highly significantly from the L1 to the L5 (see table 8).

However, the figures in table 7 do remind us that a sizable group of participants go against the general trends and do use an LX frequently for mental calculation. The preference for the L1 is thus not a law of nature but rather a reflection of averages.

Table 8. *Paired Wilcoxon Signed Ranks Tests on frequency of language choice for mental calculation across languages*

	L1/L2	L2/L3	L3/L4	L4/L5
Z	−22.10	−16.50	−7.19	−2.62
Asymp. Sig.	.0000	.0000	.0000	.0089

Three participants mentioned the topic of mental calculation in their answers to the open questions. The first participant, KK[4], a researcher, (aged 38, female, Finnish L1, English L2, Swedish L3, German L4, dominant in the L1) refers to her "absolute and total inability to calculate anything in English!" This statement may not be that surprising in itself if it wasn't that KK rates her proficiency in English to be maximally high for speaking, comprehending, reading and writing.

The second and third participants report doing mental calculation with equal ease in two languages, according to the situation. Meral, a translator, (aged 37, female, German L1, Serbian L2, English L3, Spanish L4, French L5, dominant in both the L1 and the L2) sees herself as fully multicompetent in her two dominant languages: "I even think that my Serbian and German are in a relation of linguistic schizophrenia because I can do everything in both languages—even dream, calculate and make love."

A similar view is expressed by Elisabeth, a media researcher and translator, (aged 31, female, English L1, German L2, Russian L3, French L4, Ukrainian L5, dominant in the L1 and L2): "Like many if not all bilinguals I find it hard to distinguish between my two languages. Also what language I use, write, think, speak, and calculate in depends largely upon who else is around and where I am at the time." DS, the only participant with a PhD in mathematics in the database (aged 33, male, English L1, Afrikaans L2–learnt at the age of 23) does not mention the link between his languages and mathematics, but we thought it would be enlightening to see whether he has a particular language choice for doing mental calculation. He judges his proficiency in written English to be maximal and in written Afrikaans to be very high. He also prefers to express his emotions in Afrikaans rather than in English and reports a lot of code-switching at home: "We probably argue more in Afrikaans but debate more in English." For mental calculation he reports using English all the time and Afrikaans sometimes. In other words, even a high level of proficiency in the L2 and the fact that the L2 is one of the family languages had not altered this mathematician's preference for mental calculation in the L1.

7.2. *Effect of independent variables on mental calculation within each language*

7.2.1. *The L1.* A Spearman correlation analysis shows that four out of five independent variables are linked significantly to the choice of the L1 for mental calculation (see table 9). The relationship is positive for three

Table 9. *Spearman correlation analysis between frequency of choice of the L1 for mental calculation and independent variables*

	Proficiency	Frequency	Usefulness	Comm. Anxiety
Rho	.39	.39	.22	−.20
p	.0000	.0000	.0000	.0000
N	1431	1435	1433	1404

Table 10. *Multiple regression: the strongest predictors for mental calculation in L1*

	Beta	Value of t	Value of p
Proficiency	.35	14.89	.0000
General frequency of use	.31	12.72	.0000
Usefulness	.07	2.92	.0030
Communicative Anxiety	−.06	−2.71	.0070

variables: participants with higher levels of self-perceived writing proficiency in the L1, frequent users of the L1 and participants who judged the L1 to be highly useful used the L1 more frequently for mental calculation. A negative relationship emerged between communicative anxiety in interaction with friends and choice of the L1 for mental calculation: participants with higher levels of communicative anxiety used the L1 less frequently for mental calculation.

The standard multiple regression of proficiency, general frequency of use, usefulness, communicative anxiety with friends is significant ($N = 1340$) ($R^2 = .31$, $F = 156.6$, $df(4, 1376)$, $p < .0001$). According to the criteria set out by Cohen (1992), the amount of variance (31%) explained by the model is indicative of a large effect size.

Proficiency, general frequency of use, and usefulness are significant positive predictors; communicative anxiety with friends is a significant negative predictor. Table 10 presents the exact values for the four significant predictors.

7.2.2. *The L2.* The correlation analyses investigating the relationships between frequency of use of the L2 for mental calculation and the independent variables reveal highly significant relationships: they are negative for age of acquisition and foreign language anxiety and positive for the remaining variables (see table 11).

The standard multiple regression of AoA, proficiency, general use, usefulness, foreign language anxiety, socialization, and context of acquisition is significant ($R^2 = .43$, $F = 134.9$, $df(7, 1238)$, $p < .0001$). The proportion of variance explained by the model (43%) is higher than for the L1,

Table 11. *Spearman correlation analysis between frequency of choice of the L2 for mental calculation and independent variables*

	AoA	Proficiency	Freq.	Useful	FLA	Social.	Context
Rho	−.22	.54	.57	.31	−.37	.50	.23
p	.0000	.0000	.0000	.0000	.0000	.0000	.0000
N	1359	1339	1351	1346	1294	1361	1341

Table 12. *Multiple regression: the strongest predictors for mental calculation in the L2*

	Beta	t	p
Proficiency	.23	8.71	.0000
General frequency of use	.25	7.98	.0000
Socialization	.17	6.06	.0000
Context of acquisition	.12	5.23	.0000
AoA	−.09	−3.60	.0000
Foreign language anxiety	−.09	−3.69	.0000
Usefulness	.06	2.55	.0110

Table 13. *Spearman correlation analysis between frequency of choice of the L3 for mental calculation and independent variables*

	AoA	Proficiency	Freq.	Useful	FLA	Social.	Context
Rho	−.14	.53	.59	.32	−.44	.47	.31
p	.0000	.0000	.0000	.0000	.0000	.0000	.0000
N	1052	1041	1039	1020	898	1055	1036

and reflects a large effect size (Cohen 1992). Self-perceived proficiency in writing is the strongest predictor, followed by general frequency of use, L2 socialization, context of acquisition, AoA, foreign language anxiety and usefulness (see table 12).

7.2.3. *The L3.* The picture that emerges for the L3 is remarkably similar to the one for the L2. Table 13 presents the data for the correlation analysis.

The standard multiple regression of AoA, proficiency, general use, usefulness, foreign language anxiety, L4 socialization and context of acquisition is significant ($R^2 = .43$, $F = 90.3$, $df(7, 830)$, $p < .0001$). The amount of variance explained by the model (43%) is identical to the result found for the L2. General frequency of use precedes self-perceived proficiency in writing as the strongest predictor. They are followed by context of acquisition, L3 socialization, foreign language anxiety and AoA. Perceived usefulness has no predictive value (see table 14).

Table 14. *Multiple regression: the strongest predictors for mental calculation in the L3*

	Beta	t	p
General frequency of use	.27	6.79	.0000
Proficiency	.21	6.34	.0000
Context of acquisition	.17	6.24	.0000
Socialization	.18	5.35	.0000
Foreign language anxiety	−.11	−3.40	.0010
AoA	−.06	−1.97	.0500
Usefulness	−.03	−.90	.3700

Table 15. *Spearman correlation analysis between frequency of choice of the L4 for mental calculation and independent variables*

	AoA	Proficiency	Freq.	Useful	FLA	Social.	Context
Rho	−.02	.48	.55	.55	−.36	.42	.27
p	.5911	.0000	.0000	.0000	.0000	.0000	.0000
N	728	705	722	722	546	722	720

Table 16. *Multiple regression: the strongest predictors for mental calculation in the L4*

	Beta	t	p
General frequency of use	.31	6.29	.0000
Proficiency	.21	4.77	.0000
Socialization	.17	3.80	.0000
Context of acquisition	.10	2.63	.0090
Foreign language anxiety	−.90	−2.22	.0270
Usefulness	.04	.90	.3680
AoA	.00	.05	.9570

7.2.4. *The L4.* All the independent variables—except AoA—correlate significantly with frequency of language choice for mental calculation in the L4 (see table 15).

The standard multiple regression of AoA, proficiency, general use, usefulness, foreign language anxiety, L4 socialization, and context of acquisition is significant ($R^2 = .41$, $F = 49.7$, $df(7, 502)$, $p < .0001$). The amount of variance explained by the model (41%) is almost identical to that for the L2 and L3. General frequency of use is the strongest predictor, followed by self-perceived proficiency in writing, L4 socialization, context of acquisition, and foreign language anxiety. The two remaining variables, AoA and usefulness, have no predictive value (see table 16).

Table 17. *Spearman correlation analysis between frequency of choice of the L5 for mental calculation and independent variables*

	AoA	Proficiency	Freq.	Useful	FLA	Social.	Context
Rho	−.04	.45	.52	.18	−.37	.44	.14
p	.4469	.0000	.0000	.0005	.0000	.0000	.0047
N	390	373	389	360	283	388	385

Table 18. *Multiple regression: the strongest predictors for mental calculation in the L5*

	Beta	t	p
Proficiency	.28	4.35	.0000
General frequency of use	.27	3.57	.0000
Socialization	.23	3.61	.0000
Usefulness	−.08	1.43	.1530
AoA	−.05	−.93	.3520
Foreign language anxiety	−.05	−.84	.4020
Context of acquisition	−.00	.28	.9700

7.2.5. *The L5.* The correlation analyses show that AoA is again the independent variable that is no longer linked to frequency of language choice for mental calculation. Context of acquisition remains slightly significantly linked to language choice for mental calculation (see table 17).

The patterns that emerge from the multiple regression analysis in the L5 show similarities to the ones obtained for the other languages, with some differences. The model including AoA, proficiency, general use, usefulness, foreign language anxiety, L5 socialization and context of acquisition is significant ($R^2 = .42$, $F = 24.9$, $df(7, 248)$, $p < .0001$) and explains 42% of the variance (i.e. a similar result to that obtained for the L2, L3 and L4). However, only three variables are significant predictors: self-perceived proficiency in writing, general frequency of use and L5 socialization. The four remaining variables (i.e. context of acquisition, foreign language anxiety, AoA and usefulness have no predictive value) (see table 18).

7.2.6. *The effect of gender and level of education.* The effect of these two independent variables has been calculated separately as there is no reason to expect that either variable could affect the choice of language for mental calculation. The results of the Mann-Whitney test show no systematic differences between men and women. Spearman Rank correlation analyses show a (weak) significant negative relation between education level and language choice for mental calculation in the L2 and L3 (Rho = −.07, df = 1357, $p < .015$; and Rho = −.07, df = 1057, $p < .030$); in other words, participants with higher levels of education used the L2 or L3 less frequently for mental calculation. No significant relationship appeared for the other languages. Unfortunately, no information was collected on the language of education, and more specifically the language in which literacy was learnt, as this would obviously be an important variable.

8. Discussion

The findings of the study fully support hypothesis 1, that speakers' L1 is usually the preferred language for mental calculation with monotonic decline for languages learned subsequently. Multilinguals' preference for the L1 may be linked to the fact that this specific cognitive operation has most probably been learnt in the L1, which was typically also the dominant language. This corroborates the general findings that bilinguals prefer to perform arithmetic operations in the language of instruction which is usually the L1 (cf. Bialystok 2005; Tamamaki 2003). Despite this, the answer to our first research question is negative: mental calculation does not happen exclusively in the L1. The L2 is reported, on average, to be used "sometimes" too. Moreover, three percent of participants reported "never" using the L1 anymore for mental calculation, which shows, contrary to the observation by Dehaene (1997), that L1 attrition can affect cognitive processes in the L1.

Rather than going through the hypotheses in their order of presentation, we will discuss them according to the amount of variance they predict across languages. It should be mentioned first that the seven independent variables considered in this study contributed to highly significant regression models, typically predicting slightly over 40% of variance. The model for the L1 differed from the models for the languages learned subsequently as fewer independent variables were included (AoA, context of acquisition, and socialization were not included as they were invariant or not applicable).

Frequency of general use of a language appeared to be a very strong predictor of use of a language for mental calculation across all 5 languages. Clearly, a constant use of a language can make that language become the inner language used for cognitive operations. Two participants, Meral and Elisabeth, who used their L1 and an LX with equal frequency in their daily lives, reported that they performed arithmetic operations with ease in either language, and that the language choice tended to be dictated by the situation. This finding clearly confirms the patterns uncovered by Tamamaki (1993) concerning the language choice of the Japanese-English bilinguals in five situations requiring calculations. Estimated situations of calculation in English L2 correlated positively with US residence time multiplied by their use. In other words, participants with greater general experience in English also had greater specific experience in the domain of calculation. Bernardo's (2001) Filipino–English bilinguals were also found to prefer processing numbers in their L2 English after extensive experience with this task in English.

The second independent variable to predict a significant amount of variance across the five languages is self-perceived proficiency in writing. Those participants who judged their written proficiency in a language to be high were also more likely to use that language for mental calculation. One could speculate that this is linked to the fact that literacy and numeracy typically develop together in primary education, and generally also in the same language. Someone who feels maximally competent in a language, be it an L1 or an LX, knows that he or she does not need to fear retrieval problems and that there is little risk of getting stuck because of a lack of capacity of working memory. Sociocultural researchers would probably argue that those participants who had reached high levels of proficiency in the LX had in fact internalized the LX as a tool for thinking (Lantolf & Thorne 2006).

The third independent variable to predict language choice for mental calculation is socialization in the LX. It does seem logical that the usual language of social interactions is also the preferred language for cognitive operations. The young L2 learners/users who participated in studies by Cohen (1994) and Centeno-Cortés and Jiménez Jiménez (2004) could be described as being at the start of socialization process in the L2, but none could have reached the levels of socialization experienced by many of our adult LX users. A small proportion of participants in our database who reported high levels of socialization in a LX use that language more frequently for mental calculation than those with lower levels of socialization. This result adds nuance to the finding that the L1 is the preferred language for mental calculation. Intense socialization in an LX can affect established patterns of language preference not only for emotional communication with children (cf. Pavlenko 2004) but also for complex cognitive operations like mental calculation (Tamamaki 2003).

The fourth independent variable to emerge as a significant predictor for mental calculation in the L2, L3 and L4 (but not L5) is context of acquisition. Participants who learned an LX in a classroom only are less likely to use that language for mental calculation in their adult life. Indeed, the foreign language curriculum may include numerical vocabulary but it is unlikely that the language learners would be expected to perform arithmetic operations in the LX. Those learners who reported using the LX outside the classroom during the period of instruction were much more likely to have to perform arithmetic operations in the LX (in shops, sports, or social activities). This early authentic use of the LX for arithmetic strongly contributes to later use of that LX for mental calculation. It is likely that the immersion students who participated in Cohen's (1994) study are more likely to use to their L2 for mental calculation today—if they remained in contact with Spanish—compared to non-immersion students with similar amounts of recent exposure to Spanish.

The fifth independent variable is of a purely psychological nature, namely communicative anxiety and foreign language anxiety linked to language use with friends. It emerged as a significant predictor in the L1, L2, L3 and L4 (but not L5). Not surprisingly, higher levels of communicative and/or foreign language anxiety in a language were linked to less frequent use of language for mental calculation. Derakshan and Eysenck (1998) suggest that anxious thoughts and feelings "pre-empt some of the resources of working memory, and thus impair performance when the task demands on working memory are great" (1998: 711). Mental calculation is one of the tasks where demands on working memory are very high (Ellis 1992; Noël & Fias 1998). Multilinguals will avoid using a language in which they feel more anxious as this would hamper cognitive processing and disrupt the outcome.

The sixth independent variable linked to frequency of language choice for mental calculation is perceived usefulness (for the L1 and L2). If the L1 or L2 are perceived as useful, they are more likely to be used for mental calculation, but the effect disappears for the L3, L4 and L5. This could be due to the fact that the average values for perceived usefulness of the L3, L4 and L5 are extremely low. It is likely that judgments of usefulness of a language are based on the role of that language in daily interactions. Our participants felt that their L1 and L2 were, on average, their most useful languages, therefore also the languages that they prefer to perform mental calculation in.

The last independent variable linked to frequency of language choice for mental calculation is age of onset of acquisition. This variable was a good predictor for the L2 and L3 but not for the L4 and L5. Similar patterns were found in the studies on swearing and the expression of anger among multilinguals (Dewaele 2004a, b, 2005a, 2006). It is possible that if a language is around at the time that mental calculation is being learnt, the probability of it being involved in this cognitive operation is higher. Parents who communicate with their children in another language than the school language may, for example, rehearse timetables with them in both the L1 and the L2. By the time the L4 appears, on average in late adolescence, the skill of mental calculation has been acquired, has become a routine and can be performed in the L1—or the L2/L3. Also, the likelihood of the child/adolescent needing to perform mental calculation in the L4 is much more remote. It thus seems that AoA is not necessarily the immediate neurobiological cause of the effect discovered on frequency of choice of the L2 and L3 for mental calculation, but rather an indirect effect, linked to environmental factors. A reviewer pointed out that the finding of the AoA effect for the L2 and L3 would have interesting consequences for the issue of how effective a post L3 language would be for mental calculations. This would obviously have to be based on empirical data.

Finally, gender and education level were not found to have any systematic effect on language choice for mental calculation, as could be expected. This finding can also alleviate fears about the skewed sociodemographic profile of our sample.

9. Limitations of the present study and suggestions for further research

The present design is not without its limitations. First, the fact that our data are self-reported means that we cannot automatically assume that these self-reports correspond to the reality. While a margin of error seems inevitable, research on this question has shown that self-reported measures can be considered to be reliable and valid data (MacIntyre, Noels & Clément 1997; McCroskey & McCroskey 1988). Dörnyei (2003b) pointed out that participants in questionnaire studies may want to "fake good," try to impress the researcher or try to second guess what the researcher is after. As in the present study the dependent variable, language choice for mental calculation, is rather value-neutral and since the whole data collection process was anonymous, we assume that participants filled out the questionnaire in a sincere and thoughtful manner.

The second limitation is linked to the fact that the questionnaire was not specifically designed to investigate mental calculation. Clearly, the reduction of language choice for mental calculation to a 5-point scale is inevitably a simplification of a complex picture. A follow-up study is clearly needed to obtain rich introspective data on how multilinguals shift between languages for mental calculation, both synchronically and diachronically. A specific questionnaire could differentiate between simple and more complex arithmetic. One reviewer suggested investigating the strategies used by multilinguals to solve operations between single-digit numbers—direct retrieval versus calculation; and to look for different language preferences in solving simple operations and more complex operations. Our defense of the strengths of an emic approach in bilingualism and numerical cognition should not be seen in exclusive terms. On the contrary, we have strongly defended combined etic/emic approaches (Dewaele 2005d). One could argue that the present design is somewhere in the middle of the emic/etic continuum. It is emic in the sense that all the quantitative and qualitative data are self-reports from participants, yet it is etic in the sense that values on the Likert scale were subjected to statistical analysis and the effects of different independent variables were estimated. Clearly, the present research would have benefited both from a more "emic" perspective in the guise of case studies of participants that would yield more information on language choices and strategies in everyday numerical problems (buying a newspaper, looking at house prices), and also from a more etic perspective, with more closed questions on different arithmetic operations and possibly also some numerical tests. The present study can therefore be considered to be a first step in a new direction, as well as a useful addition to the exclusive etic perspective of experimental researchers in numerical cognition and bilingualism. Finally, as the present study is not experimental, it is impossible to unambiguously pinpoint causes for particular patterns. Regression analyses allowed us to suggest that the independent variables influenced frequency of language choice for mental calculation. In this way we could infer causal relationships and assess the effect, but we could not claim that the independent variables "caused" the variation in the dependent variable because other intervening variables may be affecting both dependent and independent variables.

10. Conclusion

The present study is probably the largest of its kind on the topic of self-reported language preference for mental calculation among multilinguals. The effect of various psychological, attitudinal and social variables was estimated and compared across five languages (from L1 to L5). A remarkable similarity emerged in the predictive power of the independent variables across languages, although fewer had a significant effect in languages acquired later in life. The present design did not allow us to pinpoint the causes of the variation in language choice for mental calculation. It is very likely that complex interactions exist between various independent variables. For example, high levels of exposure and use of language are likely to boost a person's self-confidence in that language and affect the perception of usefulness. Frequent general use implies high levels of socialization. Also, naturalistic or mixed context of foreign language acquisition could point to high levels of exposure to a target language in the past, a situation that could have endured to the day of filling out the questionnaire. The effect of the independent variables may also shift according to the type of mental calculation and the size of the numerosities. More empirical and experimental studies are clearly needed in this area. Such studies are needed not just out of intellectual curiosity, but they are particularly important for knowing how to accommodate immigrant children and minority language speakers in schools (cf. Barwell, Barton & Setat 2007).

Notes

1. We would like to thank Andrew Cohen, Aneta Pavlenko, Pavel Trofimovich and the anonymous reviewers for their excellent suggestions and comments on previous versions of this study. The present research benefited from a Small Research Grant from the British Academy (SG-42593).
2. Typically from $2 + 2$ to $9 + 9$ and from 2×2 to 9×9.
3. Rusconi, Galfano & Job (in press) point out that this does not hold for all the four basic arithmetic operations.
4. Participants who wanted to remain anonymous are referred to through a 2-letter code; others are referred to using their first name.

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