The linguistic transparency of first language calendar terms affects calendar calculations in a second language

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Abstract

Calendar calculations – e.g., calculating the *n*th month after a certain month -- are an important component of temporal cognition, and can vary cross-linguistically. English speakers rely on a verbal list representation-processing system. Chinese speakers -- whose calendar terms are numerically transparent -- rely on a more efficient numerical system. Does knowing a numerically transparent calendar lexicon facilitate calendar calculations in an opaque second language? Late Chinese-English bilinguals and English native speakers performed a Month and a Weekday Calculation Task in English. Directionality (forward/backward) and boundary-crossing (within/across the year/week boundary) were manipulated. English speakers relied on verbal list processing, and were slower in backward than forward calculations. In spite of the English calendar system's opaqueness, bilinguals relied on numerical processing, were slower in across- than within-boundary trials, and under some conditions had faster RTs than the native speakers. Results have implications for research on temporal cognition, linguistic relativity and bilingual cognition.

1. Introduction

Calendar calculations are an important component of temporal reasoning which is used in everyday life, for instance in establishing on which day of which month a certain task should be completed. Conventional time units such as months and weekdays however are represented differently in different languages. Crucially, the level of linguistic transparency of calendar terms across languages varies, so that speakers of different languages perform calendar reasoning tasks differently. This effectively means that such tasks may be easier for speakers of certain languages. Do such differences and advantages remain when speakers of a language with transparent calendar terms are tested in a second language with opaque terms? A comparison of Chinese and English native speakers tested in English can help answer this question.

Whilst calendar terms in English are opaque, Chinese calendar terms represent months and weekdays as a numerical system. If knowledge of more than one language affects thinking, then native speakers of Chinese tested in English may perform calendar calculation tasks differently from English native speakers. Such a finding would have consequences for both research on temporal cognition and research on bilingual cognition.

1.1 Calendar representation and processing

In Friedman's (1983; 1984) influential view of calendar representation and processing, the months of the year are represented as a verbal sequence in a *verbal-list system*. Calendar reasoning tasks that involve calculating the exact temporal distances between two calendar units -- such as identifying the month that comes *n* months after a given month – are performed using *verbal-list processing*, by overtly or covertly reciting the sequence of units and counting them. Friedman (1983) found the following evidence for the verbal list system: 1) interference from simultaneous verbal tasks; 2) a *directionality effect*, because reciting a sequence is more difficult backward than forward; 3) a *distance effect*, because the sequential activation of units takes longer when the target is further away from the stimulus; and 4) participants' verbal reports of overt or covert reciting. However, Friedman's views of calendar representation and processing were based exclusively on data from English speakers. Since conventional time representations vary across languages, other languages may afford different ways of performing calendar calculations. An interesting comparison is that between speakers of English and speakers of Chinese.

The calendar lexicons of the Chinese and English languages have different levels of linguistic transparency. English weekday and month names are opaque (*Monday*, *January*). Chinese calendar terms instead follow a transparent numerical structure. Month names follow the format 'numeral + month', and weekdays are 'week + numeral':

一	月
yī	*yuè*
i55	jyɛ51
one	month
'January'	

星期	一
xīngqī	*yī*
ɕiŋ55.tɕʰi55	i55
week	one
'Monday'[1]	

The only non-numerical calendar term is the word for 'Sunday', which is lexicalised as 'week + *rì* or *tiān* (/z̢ɨ51/, 'sun', and /tʰiɛn55/, 'sky', respectively)'; or even just 'week'.

[1] *Xīng qī* ('week') has two synonyms, due to regional variation and levels of formality: 周 (*zhōu*, /t̢sou55/) and 礼拜 (*lǐ bài*, /li325.pai52/).

Research shows that Chinese speakers reason about months of the year and weekdays differently from English native speakers, because of the numerical transparency of the Chinese calendar naming system. Huang (1993) found that Chinese speakers perform month reasoning tasks using *numerical processing*, namely arithmetic operations. For instance, a Chinese speaker who needs to calculate which month comes five months after January (lit. 'one month') can add five to 'one month' to obtain 'six month' ('June'). Huang (ibid.) found no direction or distance effects in Chinese adults because -- unlike English speakers' verbal list strategy, which takes longer in reverse and with longer distances -- Chinese speakers' addition and subtraction require similar amounts of time. Chinese adults' numerical processing was also demonstrated by a *boundary effect*. Since arithmetics is on base-10, and months of the year are a modulo-12 list, some calendar calculations based on mental arithmetics involve crossing a boundary. For instance, calculating the seventh month after 'eleven month' (November) yields 'eighteen month', and it is necessary to subtract twelve to obtain the answer 'six month' (June). This adds one step to the process, and therefore Chinese speakers are slower with month calculations that require year boundary crossing, compared with within-boundary calculations. Jiang and Fang (1997) found the same boundary effect in weekday calculation tasks.

There is direct evidence that numerical processing is due to the transparency of Chinese calendar terms, rather than cultural or other factors. Huang (1999) compared two groups of Chinese adults, who performed calendar calculation tasks either with solar months or with the twelve units of the traditional lunar calendar, whose names are opaque (e.g. the first unit is called *dà xuě*, /ta51.ɕyɛ325/, 'heavy snow'). Participants, who came from rural areas, reported equal proficiency and frequency of use of the two calendars. Calendar calculations were faster and more accurate in the solar calendar group. Furthermore, the lunar calendar group displayed direction and distance effects, whereas the solar calendar group displayed a boundary effect. Self-reported strategies confirmed that the solar calendar group used arithmetic calculations and the lunar calendar group used verbal lists. It appears that knowledge of a numerically transparent lexicon for one type of calendar does not translate into use of numerical processing for calendar calculations in another calendar system with different units and opaque terms.

While studies reported above only tested either Chinese or English speakers, Kelly, Miller, Fang and Feng (1999) were the first to compare directly calendar calculations in Chinese and English speakers. Chinese and English-speaking primary school children and adults performed a weekday and a month-of-the-year calculation task. The Chinese group was overall faster than the English-speaking group, showed no effects of directionality, was negatively affected by boundary crossing, and mostly reported using arithmetic calculations. In comparison, English speakers were affected by directionality but not by boundary crossing, and mostly reported covert reciting. In conclusion, calendar reasoning appears to differ in Chinese and English speakers because of the linguistic transparency of the two languages' calendar lexicons. The next question is whether these two levels of transparency affect bilinguals who know numerically transparent and opaque terms for the same calendar system, when tested in the language with an opaque lexicon.

1.2 Temporal and numerical cognition in bilinguals

Much research has investigated whether learning new words or grammatical rules in a second language can result in the acquisition of new concepts and categories, or the restructuring of existing ones. These conceptual changes may happen when the first and second language carve the same continuum into different categories, for instance having two colour categories corresponding to English *blue*, or when the language groups different entities in the same category, or when the two languages require speakers to pay attention to different aspects of reality, for instance whether it is obligatory in the language to state the agent of an action or not. For example, when the second language has a linguistic label for 'orange' corresponding to colours that the native language categorises as shades of yellow or red, second language speakers may establish a new concept of 'orange' (Jameson & Alvarado, 2002). The possible outcomes of exposure to two languages are captured by the traditional distinction between subordinate, coordinate and compound bilingualism: the bilingual may have only native concepts (subordinate); two concepts, each one used when speaking the relevant language (coordinate); or an integrated concept, including features of L1 and L2 concepts (or indeed a novel concept, which is more than the sum of the concepts of either language) (compound). Researchers mostly focussed on how knowledge of more than one language may affect bilinguals' categorisation (for instance, whether something is categorised as a 'glass' or a 'cup'), attention (for instance, how much attention is paid to the endpoint of a motion event), and memory (for instance, memory for the agent of an action; for a review, Bassetti & Cook, 2011). Only limited research has investigated linguistic relativity effects on other aspects of cognition, such as reasoning and problem-solving, and on everyday, as opposed to laboratory, tasks. A study of calendar calculation addresses this gap.

While there has been no research on the effects of calendar term transparency on bilinguals' calendar calculations, two lines of previous research may be relevant: research on linguistic effects on bilinguals' temporal cognition, and research on the effects of numerical transparency on bilinguals' mathematical cognition. The former shows that bilingualism affects performance in some temporal cognition tasks; the latter shows how bilinguals perform arithmetic calculations, which is relevant to the present study's question of whether bilinguals use arithmetics for calendar calculations.

Research on the effects of bilingualism on temporal cognition has mostly focussed on mental representations of the directionality of time, linking them to the directionality of writing and to time metaphors. First, while speakers of languages that are written left-to-right conceive of time as flowing from left to right, and vice versa (Tversky, Kugelmass, & Winter, 1991), children who learn a second language that is written in opposite direction to their first language accept both directionalities for time (Kugelmass & Lieblich, 1979). Second, there is some evidence of a link between time metaphors and bilinguals' concept of time's directionality, so that native speakers of Chinese, a language with vertical time metaphors, conceive of time as flowing from left to right more the more proficient they are in English, a language that has horizontal temporal metaphors (Boroditsky, 2001; Boroditsky, Fuhrman, & McCormick, 2011; but for failures to replicate see Chen, 2007; January & Kako, 2006, among others).

The study with aims closest to those of the present study is Yang and Zhang's (2011) investigation of bilinguals' calendar calculations. The researchers tested the effects of having a linguistic label for a temporal unit in one language on bilinguals' performance in calendar reasoning in another language. The Cantonese language has a linguistic label for the time unit 'five minutes', which does not exist in Modern Standard Chinese. Cantonese-Chinese bilinguals outperformed Chinese monolinguals in calculations involving five-minute units in Chinese. Having a linguistic label for a temporal unit in one language appears to facilitate bilinguals' calendar calculations in another language. While there may be positive effects of bilingualism on temporal cognition, and more specifically Yang and Zhang (2011) have shown linguistic effects on bilinguals' temporal calculations, the effects of the numerical transparency of calendar lexicons in bilinguals have not been investigated.

Cross-linguistic research has generally demonstrated facilitative effects of numerically transparent mathematical terms on numerical cognition, particularly in comparisons of Chinese and English-speaking children (Chan, 2014; Miller, Kelly and Zhou, 2005; Ng & Rao, 2010). Chinese number words reflect the base-10 structure of the Arabic numerical system, as teen number terms follow the structure 'ten + numeral', decade terms are 'numeral + ten', and cardinal numbers are 'prefix *di* + numeral'. These different levels of transparency of mathematical terms have been linked to Chinese-speaking children's earlier acquisition of the base-ten concept and of counting skills for teen numbers, decades and ordinal numbers, compared with English-speaking peers (Fuson & Kwon, 1991; Ho & Fusan, 1998; Miller, Major, Shu & Zhang, 2000; Miller, Smith & Zhang, 2004; Miller, Smith, Zhu, & Zhang, 1995; Miura, Okamoto, Kim, Chang, Steere & Fayol, 1994), although such differences have also been attributed to cultural and educational factors (Miller, Kelly & Zhou, 2005; Ng & Rao, 2010; but see Siegler and Mu, 2008, for differences that can only be attributed to linguistic transparency). Advantages of more transparent number terms have also been found in comparisons of Italian and German children (Helmreich, Zuber, Pixner, Kaufmann, Nuerk, & Moeller, 2011), Belgian-French vs French children (Seron & Fayol, 1994), Welsh children educated in English or in Welsh (Dowker et al 2008, Dowker & Roberts, 2015), and Korean preschoolers who first learnt the opaque native Korean numerical system and later the transparent Chinese system (Song & Ginsburg, 1988). Compared with the amount of research on children, evidence of linguistic effects on mathematical abilities in adults is very limited; for instance Chinese adults outperform English adults in reversing two-digit numbers when the response is a teen number, such as reversing 71 into *seventeen* (Miller & Zhu, 1991).

Evidence of the effects of linguistic transparency on bilinguals' mathematical cognition is inconsistent. Rasmussen and colleagues (Rasmussen, Ho, Nicoladis, Leung, & Bisanz, 2006) found that Chinese-English bilingual preschoolers tested in English performed similarly to the English monolingual children tested by Miller et al. (1995). On the other hand, Han and Ginsburg (2001) found an advantage of bilingualism, as American Chinese-English bilingual high-school students outperformed English monolingual peers in understanding of geometrical concepts, thanks to the transparency of geometrical terms in the Chinese language. Looking at adult bilinguals, Chinese native-speaking Canadian adults who had been entirely educated in Canada outperformed French native peers in simple arithmetic tasks (Campbell & Xue, 2001). However, such differences may be due to cultural rather than linguistic factors, for example a stronger reliance on the use of memorised answers in the Chinese group. It appears that the bilinguals' relative proficiency in the language of counting may be more important than the level of numerical transparency of their languages (Rasmussen et al., 2006). It is then unclear whether the numerical transparency of mathematical terms in a language may facilitate mental arithmetic tasks in bilingual children and adults tested in another language. It is an open question whether native speakers of a language with numerically transparent calendar terms would use arithmetic calculations in a second language with numerically opaque calendar terms.

1.3 The present study

Previous research established cross-linguistic differences in calendar calculations, showing that native speakers of English -- a language with an opaque calendar lexicon -- rely on verbal list processing to perform calendar calculations (Friedman, 1983), whereas native speakers of Chinese -- a language with a numerically transparent calendar lexicon -- rely on numerical processing (Huang, 1993; Jiang & Fang, 1997). However, it is unclear how speakers of Chinese – whose first language has numerically transparent calendar terms – perform calendar calculation tasks in English, a language with opaque calendar terms. These Chinese-English bilinguals could rely on verbal list processing as English speakers do, showing that calendar calculations depend on characteristics of the language of the task. This would be in line with Huang's (1999) finding that Chinese speakers use numeric processing with the solar calendar, and mental-list processing with the numerically opaque lunar calendar. However, in that study the two calendars had different units. Results may be different when participants know calendars with the same units and different levels of numerical transparency.

Alternatively, bilinguals could rely on the numeric processing normally used in their native language, either by performing arithmetic calculations in English, or by performing calculations in the native language and then translating the answer. This would be in line with the bilingual advantage found by Yang and Zhang (2011) whereby Chinese speakers who know the Cantonese term for five-minute units outperform Chinese monolinguals in calculations involving such units, which do not exist in the Chinese language. Finally, bilinguals could rely on different processing and strategies depending on the demands of the task.

To answer this question, the study compared a group of Chinese instructed late learners of L2 English with a group of English native speakers, performing calendar calculation tasks in English. Two tasks, adapted from Kelly et al. (1999), required participants to calculate the *n*th month or weekday starting from a stimulus. The month calculation task was more demanding, because it required operating on seven-unit distances in a modulo-12 list, compared with four-unit distances in a modulo-7 list for the weekday calculation task.

To test for group differences, we manipulated directionality and boundary crossing. Based on evidence from English speakers (Friedman, 1983), Chinese speakers (Huang, 1993; Jiang & Fang, 1997), and comparisons of the two (Kelly et al., 1999) we made the following predictions.

1) Directionality. There were two directions: Forward and Backward. In Forward calculations, participants calculated the seventh month or the fourth day after the stimulus; in backward calculations, the target was the seventh month or the fourth day before the stimulus. If bilinguals rely on a verbal list strategy, both groups should be faster with forward than backward calculations, because verbal list processing is not suitable for backward calculations (Friedman, 1983). If bilinguals rely on a numerical strategy, they should show no effect of directionality, like the Chinese speakers tested in Chinese in Huang (1993).

2) Boundary. In Within-Boundary trials both stimulus and target were within the same month or week, whereas Between-Boundary trials required crossing a month or week boundary, such as calculating two days before Monday). If bilinguals rely on a verbal list strategy, neither group should be affected, because crossing a boundary has no additional costs for mental list reciting, and indeed English speakers are not affected by boundary crossing (Kelly et al., 1999). If however bilinguals rely on a

numerical strategy, they should be disrupted by boundary crossing, like Chinese speakers tested in Chinese (Huang, 1993; Jiang & Fang, 1997).

3) Strategies. After each set of items, participants reported their strategies. If bilinguals behave like English native speakers when tested in English, both groups should mostly report the use of verbal lists. If bilinguals behave like Chinese speakers tested in Chinese, they should report using arithmetic calculation, either in English, or in Chinese followed by translation into English.

2. Method

2.1 Participants

Participants were 18 Chinese-English bilinguals tested in China (bilingual group) and 18 English native speakers tested in the UK (English group). The groups were of similar ages ($range_{English}$: 20;0-23;7; $range_{bilinguals}$: 21;2-23;3) and gender composition (both: females = 9), who were studying non-science subjects at leading universities in China and the UK respectively. The bilingual group were majoring in English, had been studying English on average for 11 years (*SD*= 21 months), had high marks (*M* = 77%, *SD* = 5%) in the TEM-4 test, which measures the four language skills and is a prerequisite for enrolment on English majors in China, and rated their English proficiency as ‘good’ or ‘excellent’. None of the English group knew a language with a numerically transparent calendar lexicon. All participants were right-handed and reported normal or corrected-to-normal vision. Participation was voluntary and rewarded. The study received ethical approval by the Department of Education Ethics Committee at the University of York.

2.2 Materials and tasks

Calendar calculation tasks

There were two calendar calculation tasks, Month and Weekday, each with two conditions, Forward and Backward. This resulted in four sets of stimuli: Month Forward; Month Backward; Weekday Forward; Weekday Backward.

Month calculation task. Participants were informed that it takes seven months for a flower to blossom after planting, and they had to tell a farmer when his flowers would blossom knowing when they had been planted, or when they had been planted knowing when they had blossomed. Participants therefore calculated the month that was seven months after the stimulus month (Forward condition) or seven months before the stimulus (Backward condition). In both conditions, five of the twelve calculations were within the boundary of a year (Within-Boundary): e.g., flowers blossoming in August were planted in January. The other seven calculations involved crossing the December-January boundary (Across-Boundary): e.g., flowers blossoming in January were planted in June the previous year. There were 24 trials, as each month appeared once in each condition.

Weekday calculation task. Participants were informed that it takes four days for seeds to sprout after planting, and they had to tell a farmer when his seeds would sprout knowing when they had been planted, or when they had been planted knowing when they had sprouted. Participants therefore calculated the weekday that was four days after the stimulus weekday (Forward condition) or four days before the stimulus (Backward condition). Four calculations were within the boundary of a week (Within-Boundary), and three required crossing it (Across-Boundary). There were 14 trials (seven weekdays times two conditions).

Calendar calculation tasks procedure. The procedure was the same for the four sets (Month Forward, Month Backward, Weekday Forward, Weekday Backward). For each set, participants read the instructions, then performed two practice trials with the help of a researcher who provided feedback and re-run the practice trials if needed. The two practice trials were used to help participants switch between distances (four or seven units) and directions (forwards and backwards). Trials began with a black fixation point in the centre of the screen. After 500ms, the fixation point was replaced by an English month or weekday name in 48-points Chicago font, with a rightward-pointing arrow to its right in forward trials (e.g., 'January ->'), or a leftward-pointing arrow to its left in backward trials. Stimulus onset was accompanied by a ring sound. After answering orally, participants pressed a button on the response box to initiate the next trial. Answers were recorded, and RTs were subsequently manually measured on the spectrogram using Praat, as the period of silence between stimulus onset and onset of spoken answer. At the end of each of the four sets of trials, the participant described how they performed the task. Responses were later transcribed and coded. Each set of stimuli appeared once. The software randomised the order of sets, and of stimuli within each set.

Naming tasks

The *Month Naming Task* and the *Weekday Naming Task* were used to provide a baseline RT for producing English month and weekday names. A fixation point appeared in the centre of the screen for 500ms, then was replaced by a weekday or month name accompanied by a ring sound. After naming the stimulus, the participant pressed the 'next' button. In order to obtain a mean RT, each stimulus was presented twice, in random order.

Arithmetic calculation tasks

Arithmetic calculation tasks were used to test whether the two groups had comparable speeds in simple arithmetic calculations. To reflect calendar calculation tasks, there were two arithmetic calculation tasks with two directions, resulting in four sets of trials. *Seven-based additions and subtractions* consisted of adding or subtracting seven to numbers one to twelve, in line with Month Forward and Backward. *Four-based additions and subtractions* consisted of adding and subtracting four from numbers one to seven, in line with Weekday Forward and Backward. 500ms after the fixation point, an Arabic numeral appeared, accompanied by a ring sound. After answering orally, the participant pressed the 'next' button.

For both the naming and arithmetic calculations tasks, the software randomised the order of sets, and of stimuli within each set, and measured RTs from stimulus onset to button press. In order to check the reliability of these measures, the RTs of a randomly selected 10% of data (2 participants per group, total = 184 measurements, including practice trials) were measured manually from stimulus onset to oral response onset; the intraclass correlation coefficient was 0.92 [CI: 0.89,0.94], $p < 0.001$.

2.3 Procedure

Participants were tested individually in a quiet room in a 30-minute session. All participants performed tasks in the same order: Weekday Naming Task, Month Naming Task, the four sets of calendar calculation tasks (Month Forward, Month Backward, Weekday Forward, Weekday Backward) in random order (each followed by a strategy report), and then the four sets of arithmetic calculation tasks (four-based addition, four-based subtraction, seven-based addition, seven-based subtractions) in random order.

2.4 Apparatus

Tasks were programmed using the PsyScope X software (Cohen, MacWhinney, Flatt, & Provost, 1993), and administered on a PowerBook MacIntosh laptop computer. Psyscope managed stimulus presentation and randomised set and stimulus order. Participants interacted with the laptop by means of an IoLab Response Box. Oral responses were recorded using the software Praat and a Samson C01O microphone connected to the laptop via a USB port.

3. Results

3.1 Month calculation task

Preliminary analyses

Participants with less than 50% accuracy on either the forward or backward condition were excluded from the analysis (one Chinese and three English participants). RTs from incorrect responses were eliminated from the RT analysis (14.19% trials, *n*=109; four additional trials that fell outside of two *SDs* for the participant's mean for that set were eliminated as outliers).

Response times

Table 1. Mean RTs (in ms; SDs in brackets) on the Month Calculation task by group (English, Chinese-English Bilingual), Direction (Forward, Backward) and Boundary (Within, Across).

	Group	
Month calculation task	English	Chinese-English Bilingual
Forward		
within boundary	4226 (970)	4568 (1904)
across boundary	4751 (1070)	5080 (1609)
Backward		
within boundary	8979 (3296)	4154 (1330)
across boundary	8220 (2955)	6166 (2040)

RTs (see Table 1) were analysed using a mixed design ANOVA, with group (English, bilingual) as a between-group factor, and direction (forward, backward) and boundary (within, across) as within-group factors. Overall, the Bilingual group was faster than the English group, $F_1(1,30)=8.44$, $p=.007$, $r=.47$; $F_2(1,20)=71.41$, $p<.001$, $r=.88$. Forward calculations were faster than backward calculations, $F_1(1,30)=35.09$, $p<.001$, *r*=.73; F_2(1,20)=61.64, *p*<.001, *r*=.87. Within-boundary trials were faster than across-boundary ones, F_1(1,30)=5.72, *p*=.023, *r*=.40; F_2(1,20)=4.49, *p*=.047, *r*=.43. However, all the main effects were qualified by interactions. The group by direction interaction, *F1*(1,30)=25.28; *p*<.001, *r*=.68; *F2*(1,20)=94.06, *p*<.001, *r*=.91 shows that English speakers were nearly twice as fast in forward than backward calculations. The group by boundary interaction, F_1(1,30)=8.29; *p*<.007, *r*=.47; F_2(1,20)=12.27, *p*=.002, *r*=.62, was qualified by a three-way group by direction by boundary interaction, F_1(1,30)=13.12, *p*=.001, *r*=.55; F_2(1,20)=12.15, *p*=.002, *r*=.38. This shows that boundary crossing negatively affected bilinguals in the backward condition, but had no effects on English speakers or on bilinguals in the forward condition.

Accuracy

Table 2. Mean accuracy (percent correct; SD in brackets) in the Month Calculation Task by group (English, Chinese-English Bilingual), Direction (Forward, Backward) and Boundary (Within, Across).

	Group	
Month calculation task	English	Chinese-English Bilingual
Forward		
within boundary	97 (7)	89 (16)
across boundary	91 (11)	86 (16)
Backward		
within boundary	85 (16)	89 (14)
across boundary	87 (14)	74 (22)

Accuracy data (see Table 2) were analysed using a mixed design ANOVA, with group (English, bilingual) as a between-group factor, and direction (forward, backward) and boundary (within, across) as within-group factors. The English group was descriptively more accurate, and the difference approached significance in the item analysis, *F1*(1,30)=2.41, *p*=.131, *r*=.27; *F2*(1,20)=3.92, *p*=.062, *r*=.40. Forward trials were more accurate than backward trials for both groups, *F1*(1,30)=8.14, *p*=.008, *r*=.46; *F2*(1,20)=6.35, *p*=.020, *r*=.49, and there was no direction by group interaction, *F* <1. Within-boundary calculations were more accurate than across-boundary ones, *F1*(1,30)=6.95, *p*=.013, *r*=.43; *F2*(1,20)=5.95, *p*=.024, *r*=.48, and there was no boundary by group interaction, *F1*(1,30)=2.65, *p*=.114, *r*=.28; *F2*(1,20)=1.50, *p*=.235, *r*=.26. Finally, there was a three-way interaction between direction, boundary and group, *F1*(1,30)=4.45, *p*=.043, r=.36; *F2*(1,20)=4.13, p=.056, r=.41. This shows that boundary crossing negatively affected accuracy in the Bilingual group in the backward condition, but it did not affect either the native English group, or the bilingual group in the forward condition. This was in line with RT results.

Self-reported strategies

Participants' self-reported strategies were coded as 'numerical', 'verbal list', 'both' or 'other'. With forward calculations, 100% of bilingual respondents reported a numerical strategy. Among English respondents, 80% reported using verbal lists (the remaining 20% adopted a numerical strategy).

In the backward condition, both groups showed more varied strategy choices. Among bilinguals, 80% used a numerical strategy, but 20% reported mentally reciting months in their native language. Among English speakers, 60% used verbal lists, and the other 40% reported a numerical strategy, either as their sole strategy (27%) or together with verbal list (13%). The majority (86%) of English native speakers who reported covert reciting also used fingers to keep track of list reciting; however a third of them only used fingers in backward calculations. None of the bilinguals reported using fingers.

There was evidence of the difficulty of boundary crossing for the bilinguals, as some described the additional calculations required when crossing boundaries. For instance BL03 said: 'November is 11th month, so I added 7 to 11, got 18, and 18 minus 12 I got 6, so the sixth month is June'. Among the bilinguals who reported their language choices, half performed arithmetic calculations in L1 Chinese and translated the answer into L2 English, and half used L1 Chinese with more demanding conditions (backward or across-boundary) and L2 English with easier ones.

3.2 Weekday calculation task

Preliminary Analyses

Participants and trials were excluded from the RT analysis using the same criteria as in the month calculation task. This excluded one English and three bilingual participants, and 7.14% of the remaining participants' trials (*n*=32 trials).

Response times

Table 3. Mean RTs (in ms; SDs in brackets) in the Weekday Calculation task by Group (English, Chinese-English Bilingual), Direction (Forward, Backward) and Boundary (Within, Across).

	Group	
Weekday Calculation Task	English	Chinese-English Bilingual
Forward		
within boundary	2796 (597)	3209 (837)
across boundary	2903 (661)	4042 (1417)
Backward		
within boundary	4313 (1369)	3604 (994)
across boundary	4274 (1379)	5404 (1286)

RTs (see Table 3) were analysed using a mixed design ANOVA, with group (English, bilingual) as a between-group factor, and direction (forward, backward) and boundary (within, across) as within-group factors. Unlike in the month calculation task, there was a small overall advantage for the English group, which reached statistical significance in the by-item analysis, $F_1(1,30)=2.83$, $p=.103$, $r=.29$; $F_2(1,10)=18.62$, $p=.002$, $r=.81$. Forward calculations were faster than backward calculations, $F_1(1,30)=40.26$, $p<.001$, $r=.76$; $F_2(1,10)=23.23$, $p=.001$, $r=.84$, and unlike in the months task there was no group by direction interaction, $F_1(1,30)=2.39$, $p=.133$, $r=.27$; $F_2(1,10)=2.10$, $p=.178$, $r=.42$. Although within-boundary trials were faster than across-boundary trials, $F_1(1,30)=27.73$, $p<.001$, $r=.69$; $F_2(1,10)=5.37$, $p=.043$, $r=.59$, this was qualified by a boundary by group interaction, $F_1(1,30)=24.97$, *p*<.001, *r*=.67; F_2(1,10)=14.90, *p*=.003, *r*=.77. This shows that boundary crossing negatively affected bilinguals but not English speakers. Finally, the group by direction by boundary interaction approached but did not reach significance, F_1(1,30)=4.05, *p*=.053, *r*=.35; F_2(1,10)=4.76, *p*=.054, *r*=.57.

Accuracy

Table 4. Mean accuracy (percent correct; SD in brackets) in the Weekday Calculation task by group (English, Chinese-English Bilingual), Direction (Forward, Backward) and Boundary (Within, Across).

	Group	
Weekday calculation task	English	Chinese-English Bilingual
Forward		
within boundary	100 (0)	87 (25)
across boundary	97 (8)	92 (12)
Backward		
within boundary	94 (34)	91 (20)
across boundary	91 (20)	88 (10)

As Table 4 shows, both groups had very high level of accuracy. The English group outperformed the bilingual group in the by-item analysis only, F_1(1,30)=3.15, *p*=.086, *r*=.31; F_2(1,10)=7.95, *p*=.018, *r*=.67.

Self-reported strategies

Similarly to the months calculation tasks, most bilingual respondents reported using a numerical strategy (forward: 91% of respondents; backward: 82%). Unlike the more demanding month task, English respondents reported relying almost exclusively on verbal lists in both directions (both: 88%). Furthermore, only 21% of the English speakers who used verbal lists also reported using fingers in both direction, and another 36% only used fingers in the backward condition.

3.3 Naming tasks

Accuracy was at ceiling level across groups, tasks and conditions. The English native speakers had faster RTs than the bilinguals both in the Month Naming Task (M_{English} = 1,257ms, *SD* = 319; $M_{\text{Bilingual}}$ = 1,492, *SD* = 300), t_1(34)=3.31, *p*=.002, *r*=.30; t_2(11)=11.60, *p*<.001, *r*=.72, and in the Weekday Naming Task (M_{English} = 969, *SD* = 275; $M_{\text{Bilingual}}$ = 1,252, *SD* = 237), t_1(34)=2.28, *p*=.029, *r*=.25; t_2(6)=4.60, *p*=.004, *r*=.66.

3.4 Arithmetic calculations

Accuracy was at ceiling level across groups, tasks and conditions. RTs for incorrect answers were excluded from analysis (7-based calculations: 1.59% of trials, *n*=13; 4-based calculations: 0.84%, *n*=4).

RTs (Table 5) for the 7-based and the 4-based calculations were analysed using two mixed-design ANOVAs, with group (English, bilingual) as a between-subject factor, and direction (addition, subtraction) as a within-subject factor. For 4-based calculations, RTs were faster for additions (*M*=1497, *SE*=72) than for subtractions (*M*=1778, *SE*=104), $F1(1,32)=8.63$, $p=.006$, $r=.46$; $F2(1,6)=55.79$, $p<.001$, $r=.95$. For 7-based calculations, there were no main effects or interactions.

Table 5. Mean RTs (in ms; SDs in brackets) for each arithmetic calculation task (seven-based, four-based) by group (English, Chinese-English bilingual) and direction (addition, subtraction)

	Group	
Calculation task	English	Chinese-English Bilingual
Seven-based		
Addition	1968 (847)	2165 (515)
Subtraction	2245 (1036)	1951 (580)
Four-based		
Addition	1492 (420)	1502 (415)
Subtraction	1709 (626)	1846 (564)

4. Discussion

The present study tested the effects of knowing a language with numerically transparent calendar terms on calendar calculations performed in a second language with numerically opaque terms. Starting from previous evidence of differences in processing speed and strategies between native speakers of English and of Chinese speakers tested in their respective native language (Kelly et al., 1999), this study investigated how native users of the transparent Chinese calendar lexicon who are instructed late learners of English perform calendar calculations in L2 English. Our results show that Chinese speakers performing calendar calculations in English rely on numerical processing, in spite of the numerical opacity of the English calendar lexicon. Below we discuss results of the month calculation task first and then the weekday calculation task.

4.1 Month-of-the-year calculation task

When performing month calculation tasks, the Chinese speakers of English relied on numerical representation and processing, whereas the English native speakers relied on mental-list representation and processing. This difference in processing is demonstrated by differences in the two groups' RTs, directionality effects, boundary effects, and self-reported strategies, as shown below.

Response times and accuracy

Previous research (Kelly et al, 1999) found that Chinese speakers tested in Chinese were faster on month calculations than English speakers tested in English, as a consequence of the different strategies used by each group. The present study demonstrated that this advantage remains when Chinese speakers are tested in a language that has an opaque calendar lexicon. The results thus suggest that it is not the language of testing that determines bilinguals' processing and strategies. Instead, bilinguals use the faster processing of a numerically transparent first language to perform calendar calculations in an opaque L2, showing that the advantage of a transparent lexicon remains regardless of the language of testing.

The facilitative effects of knowing a numerically transparent calendar lexicon was apparent in both forward and backward conditions, but was differently manifested. In forward calculations, there were no group differences in RTs or accuracy. This means that knowing a transparent calendar lexicon allowed L2 speakers to be as fast and accurate as native speakers, despite being tested in a weaker language, with slower month and weekday naming times than native speakers. With backward calculations, bilinguals answered on average two seconds faster than native speakers; in particular, they were twice as fast as native speakers in within-boundary trials.

Research shows that L2 processing is generally slower than L1 processing, especially in late learners (Jiang, 2013; Silva & Clahsen, 2008; Trenkic and Warmington, 2018; van Gelderen et al., 2004), as also shown in this study by the bilinguals' slower RTs in the weekday and month naming tasks, compared with the English group. However, in this study L2 speakers were as fast, or even faster, than native speakers in month calculation tasks, in spite of operating in a late-learnt language they only studied as a school subject. The next section discusses the reasons of this advantage.

Negative effects of backward directionality in English speakers

Directionality effects were found in English native speakers but not in Chinese speakers of L2 English. The English group was on average twice as fast, as well as more accurate, in the forward than in the backward direction. Such effects are in line with findings by Friedman (1983) and Kelly et al. (1999). This is because, as Friedman (1983) argued, list reciting is more demanding in the backward than forward direction.

Directionality did not affect the Chinese group's RTs. This is in line with previous evidence that directionality does not affect Chinese speakers tested in Chinese (Huang, 1993; Kelly et al., 1999), and extends this finding to Chinese speakers tested in L2 English. It also confirms the use of a numerical representation-processing system, despite the lack of numerical transparency of the language of testing. And since English native speakers were considerably slowed down in backward calculations and the L2 speakers were not, this led to the bilingual group performing faster in this condition compared to the native English group.

The interaction between directionality and boundary crossing in bilinguals

The three-way interaction between group, direction and boundary revealed that boundary crossing negatively affected the bilingual group's RTs and accuracy, but only in backward calculations. Boundary crossing did not affect the English native group, confirming results in Kelly et al. (1999), probably because it involves no additional costs for verbal list processing. However, boundary crossing negatively affected the bilingual group in the backward condition, as RTs were on average two seconds slower than in within-boundary trials, and mean accuracy was just 74%. Previous research had shown that boundary crossing negatively affects Chinese speakers (Huang, 1999; Jiang & Fang, 1997; Kelly et al., 1999). The present results show that this effect remains in a different language of testing. Furthermore, the interaction between directionality and boundary crossing helps clarify the reason of the boundary effect. Boundary crossing requires an additional step, as the post-boundary figure needs to be altered to obtain the final answer. For instance, with February ('month-two') as a stimulus, the calculation is '2+7=14', which needs to be further transformed by subtracting twelve. In the backward direction, this process results in a negative number, for instance '2-7=-5'. Our results suggest that it is more difficult to resolve boundary crossing resulting in negative numbers than those resulting in positive numbers over 12.

Strategies

The analysis of self-reported strategies confirmed that the Bilingual group almost exclusively relied on a numerical strategy, whereas the English group mostly relied on a verbal list strategy. However, backward directionality and boundary crossing were linked to alternative strategies choices, and in the Bilingual group to different language choices, as more demanding conditions led participants to try different strategies.

The English group mostly reported using covert verbal list reciting, mostly using fingers to keep track. However, in the backward direction as many as 40% of English speakers used a numerical strategy as a sole or additional strategy, compared with just 20% in the forward direction. A numerical strategy for month calculation is possible because the English language conventionally represents months as numbers in written documents such as forms and cheques (Kelly et al., 1999). By collecting answers separately for each condition (backward and forward), this study clarified that some English speakers use a numerical strategy in the backward condition. This numerical strategy is less widely used than in the bilingual group, possibly because numerical representations of months are less engrained in English speakers than in Chinese speakers; however the appearance of this strategy shows that factors other than the transparency of terms can affect reasoners' strategies in calendar calculations.

In the bilingual group, all participants reported using arithmetic calculations in at least one task. This is in line with Kelly et al.'s (1999) results with Chinese adults tested in Chinese, yet differs from Huang's (1999) finding that Chinese speakers rely on mental list processing when operating with the numerically opaque lunar calendar. Reasons are unclear, but it should be noted that the Chinese solar and lunar months represent different calendar units, whereas the English and Chinese month terms are simply different labels for the same calendar unit. This may encourage Chinese speakers to use the same strategy for English and Chinese month calculations, but not for solar and lunar months. Alternatively, bilinguals in our study may have stuck to their native calendar representation and processing because they were not balanced bilinguals and were dominant in Chinese.

Although all bilingual participants used arithmetic calculations in at least one task, the complexity of calculations affected their choices of strategy and language. Indeed, 20% used verbal lists in their L1 for backward calculations, probably due to the complexity of arithmetic calculations involving boundary crossing in the backward direction. Looking at language choices, among those who used arithmetic calculations and reported their language choices, half had used English for the easier forward trials and within-boundary trials, and Chinese for the more complex ones. Note that using Chinese here involved the additional step of translating the results; however bilinguals may have preferred doing calculations in their L1, either because bilinguals generally perform better in mathematics in their most proficient language (Rasmussen et al., 2006), or because Chinese number terms are shorter and less phonologically complex than English ones (Stigler, Lee, & Stevenson, 1986). Using English may be more efficient because it eliminates the additional step of translation, but when arithmetic calculations were additionally complicated by backward boundary-crossing, some participants preferred a verbal list strategy and a language that is more established and phonologically simpler.

4.2 Weekday calculations

This study included both a weekday task and a month calculation task because participants were likely to perform differently in each. This is because weekday calculations are less demanding than month calculations, and because one weekday (Sunday) is not numerically transparent in Chinese. Below we discuss first evidence that the weekday calculation task was less demanding than the month calculation task. Then we show that in this easier task the two groups' different processing and strategies did not result in faster RTs in the bilingual group. In fact -- contrary to the month task -- the English group was marginally faster than the bilingual group.

The weekday calculation task required calculating a distance of four units in a modulo-7 list, compared with the distance of seven units in a modulo-12 list of the month calculation task. Given the smaller distance and shorter list, accuracy was at ceiling levels in both groups. Also, English native speakers were descriptively almost twice as fast in the weekdays than in the month calculation task, and Chinese-English bilinguals were also faster, albeit less markedly so.

In this easier task, the English group was slightly faster and more accurate than the bilingual group. Verbal list processing is probably efficient enough for this task, and arithmetic calculations did not confer an advantage to the bilinguals. Native speakers outperformed late bilinguals, which is the normal outcome when native and non-native speakers perform a simple task in the same language, but the difference was very small.

Boundary crossing again only affected the bilingual group, confirming that the Chinese speakers were using numerical processing even in this easier task. However, unlike the month task, bilinguals were negatively affected in both directions. This may be because calculations that involve crossing the weekday boundary also necessarily involve Sunday, whose name is not numerically transparent, as it is 'week-sun' rather than 'week-seven'.

The analysis of reported strategies confirmed the English group's preference for verbal lists, and the Bilingual group's preference for numerical strategies. However, compared with the month calculation task, only a small number of English participants tried a numerical strategy, either because the verbal list strategy was successful, or because -- unlike months -- weekdays are not represented with numbers in written English. The percentage of bilinguals who reported a verbal list strategy was similar to the month calculation task. Verbal list reciting in English could have avoided the extra step of translating the result of the calculation, the difficulty of crossing boundaries, and the difficulty of dealing with one weekday term that is not numerically transparent. However, it appears that when a task is easy participants feel no need to try alternative strategies, as reasonable performance can be obtained with whichever strategy they normally use.

4.3 Summary of findings

In summary, we found that the linguistic transparency of the calendar lexicon in one language affects calendar calculation tasks performed in another language with an opaque calendar lexicon. When performing calendar calculations tasks in their second language, Chinese-English bilinguals used a strategy – numerical processing – more readily afforded by their native language. This is demonstrated by the negative effects of backward boundary crossing (which resulted in negative numbers) on both speed and accuracy, the absence of a directionality effect, and strategy reports. The advantage of knowing a numerically transparent calendar lexicon were such that they outweighed the disadvantage of being tested in a weaker language with slower calendar term naming than native speakers. Therefore, the native speakers only marginally outperformed Chinese-English bilinguals in RTs and accuracy in the weekday calculation tasks, where verbal list reciting was successful thanks to small distances and a short list. However, month backward calculations, bilinguals were even faster than English native speakers, as a consequence of using a numerical representation-processing system afforded by the numerical transparency of Chinese calendar terms, whereas English speakers relied on a verbal list representation-processing system which is less efficient in the backward direction. This shows that performing in a second language does not always result in slower processing.

5 Conclusions and implications

The present findings suggest that the numerical transparency of a language's calendar lexicon affects calendar calculations, as Chinese-English instructed late bilinguals and English native speakers performed the same task in the same language using different strategies. The results support the view that the languages we speak can affect how, and how easily, we perform specific reasoning tasks. Below we discuss implications for temporal reasoning research, linguistic relativity research, and bilingual cognition research.

5.1 Implications for temporal reasoning research

Results confirmed previous evidence of cross-linguistic differences in calendar calculations and extended it by showing that such differences persist regardless of the language of testing, as follows. Our findings confirm that reliance on the verbal list representation-processing system proposed by Friedman (1983, 1984) is not universal but specific to native speakers of English, and presumably to speakers of other languages with a similarly opaque calendar lexicon. Furthermore, this reliance is also not found in speakers of English who know a language with numerically transparent terms.

Results also demonstrated the linguistic rather than cultural nature of these cross-linguistic differences in calendar calculations. Unlike differences in performance in mathematical tasks (Miller, Kelly & Zhou, 2005; Ng & Rao, 2010), differences in calendar calculations cannot be attributed to different cultural or educational practices, because they are not taught or tested. Also, the bilinguals' preference for numerical strategies cannot be attributed to differences in arithmetic skills, because the two groups did not differ in the arithmetic calculation tasks. The most likely explanation is the level of transparency of the English and Chinese calendar lexicons.

5.2 Implications for linguistic relativity research

Results contribute to research on linguistic relativity by revealing an effect of linguistic transparency on an aspect of temporal reasoning – calendar calculations – which has not been investigated in bilinguals before. Findings are evidence of linguistic relativity because a strategy developed due to characteristics of one language is being used to perform a task in another language.

This study has a bearing on a crucial debate in linguistic relativity research, namely whether linguistic tasks can constitute evidence of linguistic relativity. Although there is a view that linguistic relativity can only be demonstrated by non-linguistic tasks, some reasoning tasks – such as calendar calculations tasks -- can only be performed through language. Therefore tasks that involve language have ecological validity. The study also shows that research on bilinguals is crucial to claims of a causal relationship between language and thought. By testing bilinguals, researchers can compare speakers of different languages while testing them in the same language, thus eliminating the confound of the language of testing. When the language of testing is the same across groups, differences in performance are more likely to be due to different processes and strategies than when different groups answer in different languages.

5.3 Implications for bilingual cognition research

Whilst most research on adult L2 learners and late bilinguals tends to demonstrate slower processing compared with native speakers of the target language, the present study shows that instructed late bilinguals performing a reasoning task in their second language can be faster than native speakers. It appears that the disadvantages inherent in performing in a weaker language are eclipsed in importance when the task is sufficiently complex, and the native language affords a more efficient way of solving it. Future research on late bilinguals and L2 learners should investigate more complex tasks than the simple tasks normally investigated by linguistic relativity researchers.

The study also contributes to debates about the cognitive consequences of bilingualism. The traditional distinction between sequential, coordinate and compound bilinguals implies a hierarchy from failure to assimilate the L2 concepts, to the acquisition of two separate concepts, to the development of a novel concept; the traditional concept of transfer also implies an inability to perform like a native speaker of the target language. However, reliance on the native language does not necessarily imply an inability to acquire modes of thought associated with the target language. In the case of the present study, since the native language affords a more efficient strategy, there is no reason to adopt the less efficient strategy of the second language. The bilingual is a multi-competent individual (Cook, 2012) who has a variety of solutions offered by their various languages at their disposal, and can choose the most efficient one for the task at hand.

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