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The influence of time units on the flexibility of the spatial numerical association of response codes effect

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The *Spatial Numerical/Temporal Association of Response Codes (SNARC/STEARC) effects* are considered evidence of the association between number or time and space, respectively. As the SNARC effect was proposed by Dehaene, Bossini, and Giraux in 1993, several studies have suggested that different tasks and cultural factors can affect the flexibility of the SNARC effect. This study explored the influence of time units on the flexibility of the SNARC effect via materials with Arabic numbers, which were suffixed with time units and subjected to magnitude comparison tasks. Experiment 1 replicated the SNARC effect for numbers and the STEARC effect for time units. Experiment 2 explored the flexibility of the SNARC effect when numbers were attached to time units, which either conflicted with the numerical magnitude or in which the time units were the same or different. Experiment 3 explored whether the SNARC effect of numbers was stable when numbers were near the transition of two adjacent time units. The results indicate that the SNARC effect was flexible when the numbers were suffixed with time units: Time units influenced the direction of the SNARC effect in a way which could not be accounted for by the mathematical differences between the time units and numbers. This suggests that the SNARC effect is not obligatory and can be easily adapted or inhibited based on the current context.

The study of the relationship between numerical reasoning and spatial representations received minimal attention until Galton developed his ideas about the spatial properties of numbers (Galton, 1881). Since then, researchers have begun to study spatial aspects of number processing from various perspectives. For instance, Dehaene, Bossini, and Giraux (1993) observed a correlation between response side and number

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magnitude: When assessing the parity (odd/even) of Arabic numerals from zero to nine, the response time (RT) is shorter on the left side than on the right side for small numbers, whereas the opposite pattern is observed for large numbers. This phenomenon is called the Spatial Numerical Association of Response Codes effect (SNARC effect).

As Dehaene *et al.* (1993) proposed the SNARC effect, it has aroused the interest of an increasing number of researchers. Extensive research revealed that the SNARC effect applied not only to numbers but also to other stimuli, such as non-numeric sequence information (Dehaene *et al.*, 1993; Dodd, Van der Stigchel, Adil Leghari, Fung, & Kingstone, 2008; Fischer, 2003; Gevers, Reynvoet, & Fias, 2003; Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Ishihara, Keller, Rossetti, & Prinz, 2008; Ito & Hatta, 2004; Zorzi, Priftis, Meneghello, Marenzi, & Umiltà, 2006), angle magnitude (Fumarola *et al.*, 2014; Ren, Nicholls, Ma, & Chen, 2011), auditory pitch (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006), luminance magnitude, physical size, conceptual size, and auditory intensity (Ren *et al.*, 2011). Studies also indicated that processing time and temporal duration are coded similarly to other quantities, in that a short temporal duration was responded to faster with the left hand and slower with the right hand. Those temporal effect is referred to as the spatial–temporal association between response codes [STEARC] effect (Bonato, Zorzi, & Umiltà, 2012; Casasanto & Boroditsky, 2008; Di Bono *et al.*, 2012; Fabbri, Cancellieri, & Natale, 2012; Ishihara *et al.*, 2008; Vallesi, Binns, & Shallice, 2008; Vallesi, Mcintosh, & Stuss, 2011).

The SNARC effect exhibits considerable contextual flexibility (Bächtold, Baumüller, & Brugger, 1998; Burr, Ross, Binda, & Morrone, 2010; Dodd *et al.*, 2008; Gevers & Lammertyn, 2005; Ito & Hatta, 2004; Nuerk, Weger, & Willmes, 2001; Ristic, Wright, & Kingstone, 2006; Schwarz & Keus, 2004; Tlauka, 2002). Dehaene *et al.* (1993) showed that the SNARC effect is dependent on the context within which the number is currently presented (see also Fias, 1996). For example, the same number (4) can be responded to more quickly on the left or the right side, when it is presented within the context of a different range of numbers in which it is in the lower half (1-9) or in the upper half (1-5), respectively. In the research of Bächtold *et al.* (1998), they asked participants to respond to numbers ranging from 1 to 11, within two imagined contexts, as distances on a ruler or as hours on an analog clock face. For example, when the number 4 was imagined as distance on the ruler, the reaction on the left side was faster than on the right side, and when it was conceived as hours on an analog clock face, the reaction on the right side was faster than on the left. The results indicated that the SNARC effect was observed in the ruler condition, whereas a reverse SNARC effect was observed in the analog clock face condition. This indicates that spatial coding of magnitude can be dynamically adjusted to the context. In summary, when the spatial frame of reference differs, the SNARC effect for numbers changes accordingly (Bächtold *et al.*, 1998; Ristic *et al.*, 2006; Rusconi *et al.*, 2006; Vuilleumier, Ortigue, & Brugger, 2004).

Interindividual sources of variability, such as reading and writing conventions in different cultures (Ariel, Al-Harthy, Was, & Dunlosky, 2011; Casasanto & Bottini, 2010; Chen & Verguts, 2010; Shaki, Fischer, & Petrusic, 2009; Zebian, 2005) and learned finger-counting strategies (Di Luca, Granà, Semenza, Seron, & Pesenti, 2006), can also influence the orientation of the SNARC effect. In these studies, the association of number with space in English, Arabic, and Japanese participants was mediated by culture; the orientation of SNARC effect followed the culturally acquired reading or scanning habits. Lindemann, Abolafia, Pratt, and Bekkering (2008) suggested that coding strategies serve an important role in the cognitive link between numbers and space. In their study, participants had to remember three types of Arabic digit strings: a left-to-right ascending number sequence (e.g., 3-4-5), a descending sequence (e.g., 5-4-3), or a disordered sequence (e.g., 5-3-4). When the participants were asked to indicate the parity status digit (i.e., 1, 2, 8, or 9) with a left/right keypress response, the SNARC effect was mediated by the coding requirements of the memory tasks: It was only present after memorizing the ascending or disordered number sequences and disappeared after processing descending sequences.

As discussed in the preceding literature review, previous studies of the flexibility of the SNARC effect have been limited to manipulation of a single number or non-numerical information (Calabria & Rossetti, 2005; Casasanto & Boroditsky, 2008; Dehaene *et al.*, 1993; Di Bono *et al.*, 2012; Dodd *et al.*, 2008; Fabbri *et al.*, 2012; Fumarola *et al.*, 2016; Gevers *et al.*, 2003; Ishihara *et al.*, 2008; Ren *et al.*, 2011; Vallesi *et al.*, 2008, 2011; Wood, Mahr, & Nuerk, 2005; Zorzi *et al.*, 2006). However, numbers are customarily linked to concrete items or abstract concepts (e.g., one book, two trees) in real life. Thus, previous theoretical assumptions may be insufficient to account for processing of numbers when they are combined with context information. Relatively few studies have examined the interaction among numbers, associated background information or units of measurement (e.g., 1 kg), and duration estimation (Lu, Hodges, Zhang, & Zhang, 2009; Oliveri *et al.*, 2008). Hartmann and Mast (2017) noted that loudness interacts with the processing of numbers: A quiet voice facilitated the left response to small numbers, and a loud voice facilitated the right response to large numbers. The result indicated that background information (e.g., the voice) can influence the processing of numbers.

From the above literature review, we know that the SNARC effect is flexible and can be affected by different factors. In this study, we tested the hypothesis that non-numerical magnitude information will influence the flexibility of SNARC effect when numbers are combined with it. We employed Arabic numbers that were suffixed with time units (e.g., 7秒miǎo and 6分fēn, which represent 7 s and 6 min in English, respectively) and a magnitude comparison task to explore the flexibility of the SNARC effect for numbers. Because numbers and time units have unique magnitudes, the main hypothesis we tested in this study is that the SNARC effect on numbers will be adjusted by the suffixed time unit. The reading and writing convention for time units in Chinese was also considered in the experiments. If time units influence the SNARC effect, the directionality of the SNARC effect may be driven by two characteristics of the time unit: the magnitude or the reading and writing convention of the unit. In Chinese, date format is from large unit to small unit – for example, 30 November 2016 is written as 2016年(nián/year) 11月(yuè/month) 30日(rì/day). If the directionality of the SNARC effect follows these Chinese reading and date format conventions, numbers with larger time units should be preferentially processed when presented to the left side, and numbers with small time units should show a similar bias for the right side.

In Experiments 1a and 1b, the Arabic numbers (1–9) and Chinese time units (秒miǎo/second - 年nián/year) were tested, respectively. During the magnitude comparison tasks, the standard stimulus was 5 in Experiment 1a and天(tiān/day) in Experiment 1b. The purpose of this experiment was to establish the SNARC effect of number and the STEARC effect of time units for these stimuli. Experiment 2 examined the flexibility of the SNARC effect when a number was suffixed with a time unit. In Experiment 2, three types of materials were tested separately: (2a) The number and time unit increased from opposite directions (7秒miǎo/seconds - 1年nián/year), and 4天(tiān/days) was the standard stimulus; (2b) the number was suffixed with the same time unit (1时shí/hour - 5 时/hours -

9 时/hours) or different time units (1天tiān/day - 5时/hours - 9天tiān/days), with the standard stimulus of 5时(shí/hours). Experiment 3 investigated the flexibility of the SNARC effect when a number is near the level of changing unit order (60) of the time unit 分(fēn/minute). The comparison stimuli were 56分(fēn/minutes) - 64分and the standard stimuli were 1时(shí/hour) and 60时.

EXPERIMENT 1a

Experiment 1 was conducted to replicate the SNARC effect of numbers in 1a and STEARC effect of time units in 1b and establish the presence of the effect for the stimuli used in these studies. We predicted that a smaller magnitude would be responded to faster on the left-hand side, whereas a larger magnitude would be responded to faster on the right-hand side. We hypothesized that if the writing and reading conventions for Chinese time unit affected processing in 1b, that the reverse response pattern would be found.

Method

Participants

Healthy college students ($N = 28$) from South China Normal University participated in the experiment (12 males, mean age = 21 years, range = 18–23 years). All subjects were right-handed. Their native language was Chinese, and they had normal or corrected-to-normal vision. They were paid ten Yuan for their participation. Before we conducted the study, we obtained ethical approval from the Institutional Review Board (IRB) of South China Normal University. All participants provided written consent to participate.

Materials and procedure

The study materials were Arabic numerals (1–9) representing small numbers (1, 2, 3, 4) and large numbers (6, 7, 8, 9), with the standard stimulus being the number 5. The procedure followed the classic magnitude comparison task, where subjects compare target numbers with 5 to judge whether they are larger or smaller than 5 (Cao, Li, & Li, 2009; Dehaene, 1996; Liu, Tang, Luo, & Mai, 2011; Temple & Posner, 1998). A fixation cross (+; 300 ms) was presented in the centre of the screen. A number was then presented randomly from 500 to 1,200 ms, and the participants were asked to judge numerical magnitude. If the number was smaller than 5, they pressed F with the index finger of the left hand; if it was larger than 5, they pressed J with the index finger of the right hand. They completed the reverse pattern in the second block, and the response side for small versus large number magnitudes was counterbalanced within the subjects. The order of tasks was counterbalanced between subjects. Each block contained 240 stimuli, and the entire experiment consisted of 480 trials. There were 16 practice trials before the formal experiment, and each stimulus was repeated 30 times in a block. There was a break of a few minutes between these two blocks. The entire experiment took about 15 min to complete.

Results and Discussion

The average error rate for RTs was 3.8%; there was no speed–accuracy trade-off, r (28) = +.40, $p < .05$. We excluded trials in which the RT was <100 ms or more than 1,000 ms. Trials were also excluded when the average RT was beyond 2.5 standard

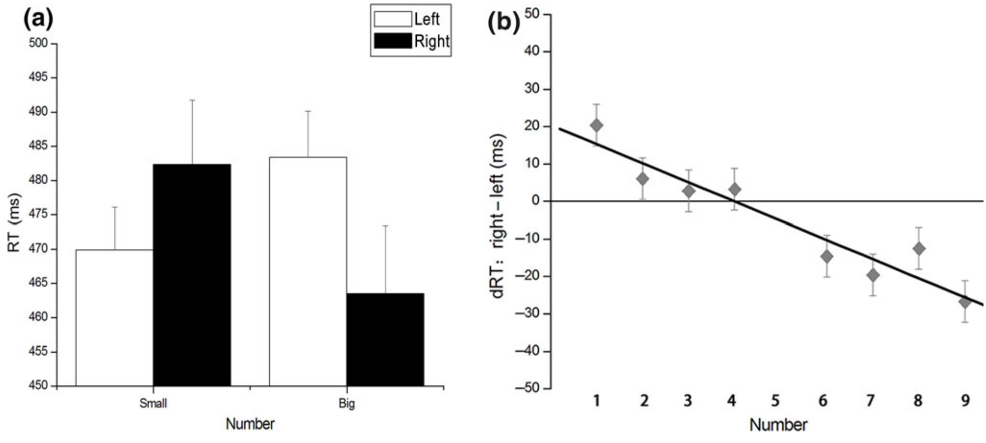

Figure 1. Mean reaction time (ms) and reaction time difference scores (dRT) for the stimuli of small magnitudes and large magnitudes in Experiment 1a. (A) represents the mean results; (B) represents the dRT (RT right response minus RT left response) result of number. The dRT regression line and the observed data separately represent the different reaction times between the right response and the left response. The error bars indicate standard errors of measurement.

deviations of the sample average. In the final sample, data for 28 subjects were analysed. The average correct RTs for numbers 1, 2, 3, 4, 6, 7, 8, and 9 were 466, 461, 474, 494, 488, 475, 462, and 460, respectively.

The data were then analysed for the effect of magnitude (2: large, small) × response (2: left, right) in a repeated-measures analysis. The main effect of magnitude was not significant, $F(1, 27) = 1.73$, $p = .20$, whereas a marginal significant main effect of response side was found, $F(1, 27) = 3.59$, $p = .07$, $\eta_p^2 = .12$. The mean RT of right-side responses was faster than that of left-side responses. The interaction between the number magnitude and the response side was also significant (Figure 1A), $F(1, 27) = 13.16$, $p < .01$, $\eta_p^2 = .34$, which provides evidence of the SNARC effect. To study this effect further, we conducted a regression analysis with the RT difference (right-hand response minus left-hand response) for each number as the dependent variable. Following the method recommended by Lorch and Myers (1990), we identified a reliable SNARC effect that had a negative slope value: −6.33, $t(27) = -8.77$, $p < .001$, confidence interval (95%) [−7.75, −4.90] (Figure 1B).

The results indicated a robust SNARC effect for number processing, replicating previous studies and providing a foundation for the subsequent experiments. The response condition of the side differed for numbers; small numbers were reacted to faster on the left-hand side, whereas large numbers were reacted to faster on the right-hand side. Experiment 1b explored the SNARC effect of Chinese time units.

EXPERIMENT 1b

Method

Participants

For this experiment, 26 undergraduate students (12 males) were selected. Their mean age was 22.5 years, and 19 of the participants were right-handed. They are all native Chinese and had normal or corrected-to-normal vision. As in Experiment 1, the participants were paid 10 Yuan after the experiment.

Materials and procedure

The standard stimulus was 天(tiān), which means day in English, and the comparison stimuli were 秒(miǎo), 分(fēn), 时(shí), 周(zhōu), 月(yuè), and 年(nián), which mean second, minute, hour, week, month, and year in English, respectively. The procedure was similar to Experiment 1a; however, in this experiment, we asked the subjects to determine whether the order of the units were smaller or larger than 天(tiān/day). The evaluation task and counterbalancing were similar to Experiment 1a. Each block contained 180 stimuli, and the entire experiment consisted of 360 trials. There were 18 practice trials before the formal experiment, and each stimulus was repeated 30 times in a block. A break of a few minutes was arranged after the completion of the first block. The entire experiment took about 10 min to complete.

Results and Discussion

Data analysis methods were the same as in Experiment 1a. The average RTs of the time units 秒(miǎo/second), 分(fēn/minute), 时(shí/hour), 周(zhōu/week),月(yuè/month), 年(nián/year) were 502, 515, 534, 509, 519, and 505, respectively. The results of Experiment 2 showed that the main effect of time unit magnitude was marginally significant, $F(1, 25) = 4.09, p = .05, \eta_p^2 = .14$. Moreover, the main effect of response side was significant, $F(1, 25) = 6.05, p < .05, \eta_p^2 = .20$, with right-side responses being faster than left-side responses. A significant interaction occurred between the time units and the response direction (Figure 2A); $F(1, 25) = 9.32, p < .01, \eta_p^2 = .27$. The dRT (RT right response minus RT left response) result for non-continuous stimuli was consistent with Experiment 1 except that the independent variables were small and large, which means that the stimuli were categorized into two types: small units (秒/second, 分/minute, 时/hour) and large units (周/week, 月/month, 年/year). The dRT results of the time unit in this experiment are presented in Figure 2B.

The results provide evidence that Chinese time units, as numerical information, have a relationship with mental space. Responses for small time units (秒, 分, 时)

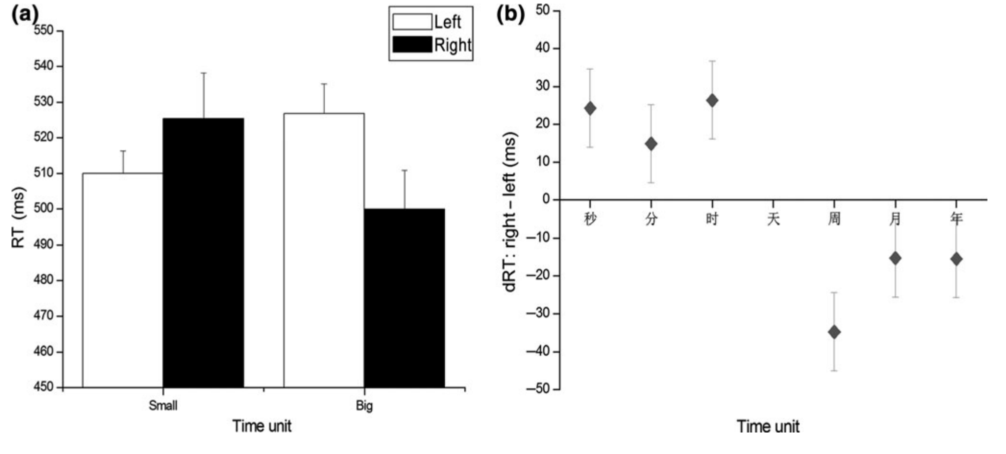

Figure 2. Mean reaction time (ms) and reaction time difference scores (dRT) for the stimuli of small magnitudes and large magnitudes in Experiment 1b. (A) represents the mean results; (B) represents the dRT (RT right response minus RT left response) result of each stimulus. The error bars indicate standard errors of measurement.

were faster when they were responded to with the left hand, whereas responses for large time units (周, 月, 年) were faster when they were responded to with the right hand. Although Chinese date format is written with large time units preceding small time units in Chinese (e.g., 2014年nián 12月yuè 6日rì/is 6 December 2014 in American style), these results indicate that the customary writing order did not influence the STEARC effect, indicating that the magnitude effect of units is greater than any such writing and reading convention effect. These results provide an empirical and theoretical basis for exploring the flexibility of numbers when they are suffixed by time units.

EXPERIMENT 2a

Experiment 2 aimed to explore the situation in which a number was suffixed with a time unit. Three types of stimuli were separately presented in Experiments 2a and 2b: (2a) 7秒(miǎo/seconds) to 1年 (nián/year), the standard stimulus was 4天(tiān/days); (2b) numbers were suffixed with the same time unit (1时shí/hour - 5时shí/hours - 9时) and different time units (1天tiān/day - 5时shí/hours- 9天); the standard stimulus was 5时shí/hours. All the compared stimuli were presented in random order. The assumption in this part was that if the SNARC effect is sensitive only to number, the effect should not change as the suffixed time unit varies. If the conventional reading and writing direction for time units influences the effect, a large time unit with a small number should be responded to faster with the left hand and vice versa. Other patterns would indicate that the SNARC effect is flexible when a number is suffixed with a unit and the magnitude information of both is important.

Method

Participants

A group of 26 new native Chinese with normal or corrected-to-normal vision participated in the experiment (14 were female, 23 were right-handed, and the average age was 21.5 years). Their native language was Chinese, and 10 Yuan was given as payment after the experiment.

Materials and procedure

The experimental materials were combinations of numbers (1–7) with time units, in which the magnitude of the numbers decreased, while the magnitude of the time units increased: 7秒(miǎo), 6分(fēn), 5时(shí), 4天(tiān), 3周(zhōu), 2月(yuè), and 1年(nián), which means 7 s, 6 min, 5 hr, 4 days, 3 weeks, 2 months, and 1 year. The standard stimulus was 4天(tiān/days), and the other stimuli were used for comparison. The procedure for this experiment was the same as the procedures used in Experiments 1a and 1b.

The participants were asked to determine whether the presented combination was larger or smaller than 4天(tiān/days). If it was smaller, they pressed F key; Otherwise, they pressed J key. In the subsequent block, this response assignment was reversed. The order of tasks and blocks was counterbalanced across participants. Each block contained 180 stimuli, and the entire experiment consisted of 360 trials. There were 18 practice trials before the formal experiment, and each stimulus was repeated 30 times in a block. After completion of the first block, a break of a few minutes was given to the participants. The entire experiment took about 10 min to complete.

Results and Discussion

The same method as in Experiments 1a and 1b was used to analyse the data. The average RTs of the stimuli 7秒(miǎo/second), 6分(fēn/minutes), 5时(shí/hours), 3周(zhōu/weeks), 2月(yuè/months), and 1年(nián/year) were 499, 506, 532, 514, 511, and 506 ms, respectively. We found the main effect of response side was not significant, $F(1, 25) = 2.08, p = .16$, nor was the main effect of the overall magnitude of the stimuli, $F(1, 25) = 0.13, p = .72$. The interaction between the stimulus magnitude and the response side was significant (Figure 3A): $F(1, 25) = 16.97, p < .001$, and $\eta_p^2 = .40$. Figure 3B shows the dRT result for the combination of number with time unit.

The results of Experiment 2a revealed that the SNARC effect was reversed and the STEARC effect was dominant when numbers were suffixed with time units. Responses to small numbers with large time units (3周zhōu/weeks, 2月yuè/months, 1年nián/year) were faster when the right hand was used to react, whereas responses to large numbers with small time units (7秒miǎo/seconds, 6分fēn/minutes, 5时shí/hours) were faster when they were responded to with the left hand.

As in Experiment 1b, the conventions by which Chinese time units are expressed had no effect in this experiment; a number with a large time unit was not responded to faster on the left side. Thus, the effect of magnitude information may be more important for the association of number with space when it was suffixed with a time unit. In this study, there was a conflict in magnitude between number and time unit. The results may be attributed to a combined magnitude of both the number and time unit together, or the time unit alone. Although the participants told us they indeed considered both the number and time unit in the debriefing questionnaire after Experiment 2a, data were needed to demonstrate that either combination or the time unit influences the SNARC effect. Experiment 2b was conducted to distinguish between these possibilities.

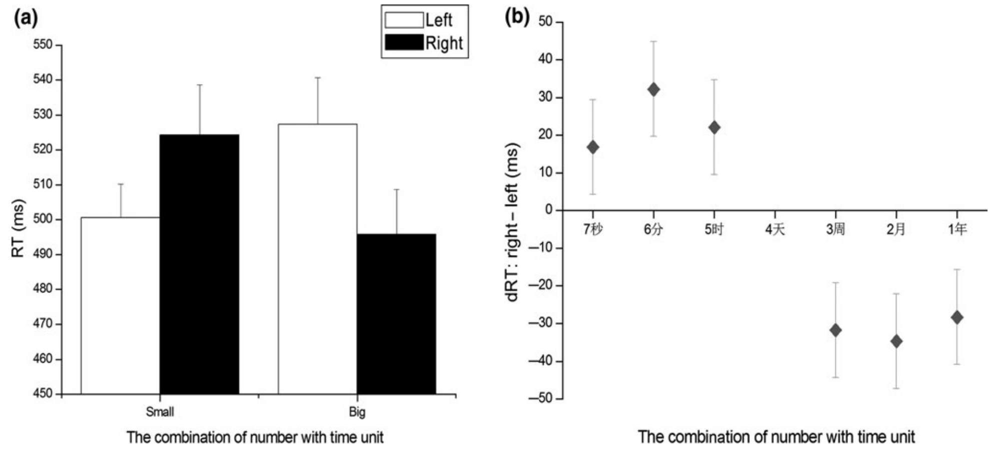

Figure 3. Mean reaction time (ms) and reaction time difference scores (dRT) for the stimuli of small magnitudes and large magnitudes in Experiment 2a. (A) represents the mean reaction time result of Experiment 2a; (B) represents the dRT result of Experiment 2a. The error bars indicate standard errors of measurement.

EXPERIMENT 2b

Method

Participants

A new group of 27 (15 female) undergraduates participated in the experiment. The average age was 22.5 years, 18 participants were right-handed, and they were given 10 Yuan after the experiment.

Materials and procedure

The experimental materials were combinations of small numbers (1, 2, 3, 4) or large numbers (6, 7, 8, 9) with two time units: 时shí/hour (1时- 9时) and 天tiān/day (1天- 9天). The standard stimulus was 5时 (shí/hour). We employed other stimuli that consisted of numbers (range: 1–4) with other time units, namely 秒(miǎo/second) and 分fēn/minute (1秒 - 4秒; 1分 - 4分), to balance the number of large and small responses. These four types of stimuli (1时shí/hour – 9时; 1天tiān/day – 9天; 1秒miǎo/second – 4秒; and 1分fēn/minute – 4分) were presented in random order to the participants.

The procedure was consistent with those of the previous experiments; however, we asked the participants to judge whether the stimulus was larger than 5时/hours. If the target stimulus was smaller, they pressed F; otherwise, they pressed J. In the subsequent block, the response assignment was reversed. The order of tasks and blocks was counterbalanced across participants. There were two parts in each block; each part consisted of 360 stimuli. Each block contained 720 stimuli, and the entire experiment consisted of 1,440 trials. There were 24 practice trials before the formal experiment, and each stimulus was repeated 30 times in the experiment. The participants were allowed a break of a few minutes after they finished one part. The entire experiment took about 30 min to complete.

Results and Discussion

Consistent with the previous experiments, the hour and day stimuli were analysed separately. The average RTs for the stimuli 1时(shí/hour), 2时, 3时, 4时, 6时, 7时, 8时, and 9时 were 560, 559, 563, 586, 568, 545, 539, and 538 ms, respectively. There was a significant main effect of magnitude, $F(1, 26) = 23.07$, $p < .001$, $\eta_p^2 = .47$. By contrast, the main effect of response side was not significant, $F(1, 26) = 0.35$, $p = .56$. Moreover, the interaction between the magnitude and the response side was significant (Figure 4A), $F(1, 26) = 4.54$, $p < .05$, and $\eta_p^2 = .15$. The figure of dRT of the number with 时(shí/hour) is presented in Figure 4B.

The average RTs for the stimuli 1天(tiān/day), 2天, 3天, 4天; 6天, 7天, 8天, and 9天 were 555, 537, 533, 536, 517, 504, 500, and 503 ms, respectively. We found a significant main effect of magnitude, $F(1, 26) = 185.70$, $p < .001$, $\eta_p^2 = .88$. The main effect of response side (L or R) was significant, $F(1, 26) = 15.30$, $p < .005$, $\eta_p^2 = .37$. The interaction between magnitude and response side was not significant (Figure 4C), $F(1, 26) = 0.06$, $p = .81$, $\eta_p^2 = .002$. The figure of dRT of the number with天(tiān/day) is presented in Figure 4D.

In Experiment 2b, the SNARC effect was only observed in stimuli in which the numbers were suffixed with the same time unit (1时shí/hour - 5时- 9时). For the stimuli in

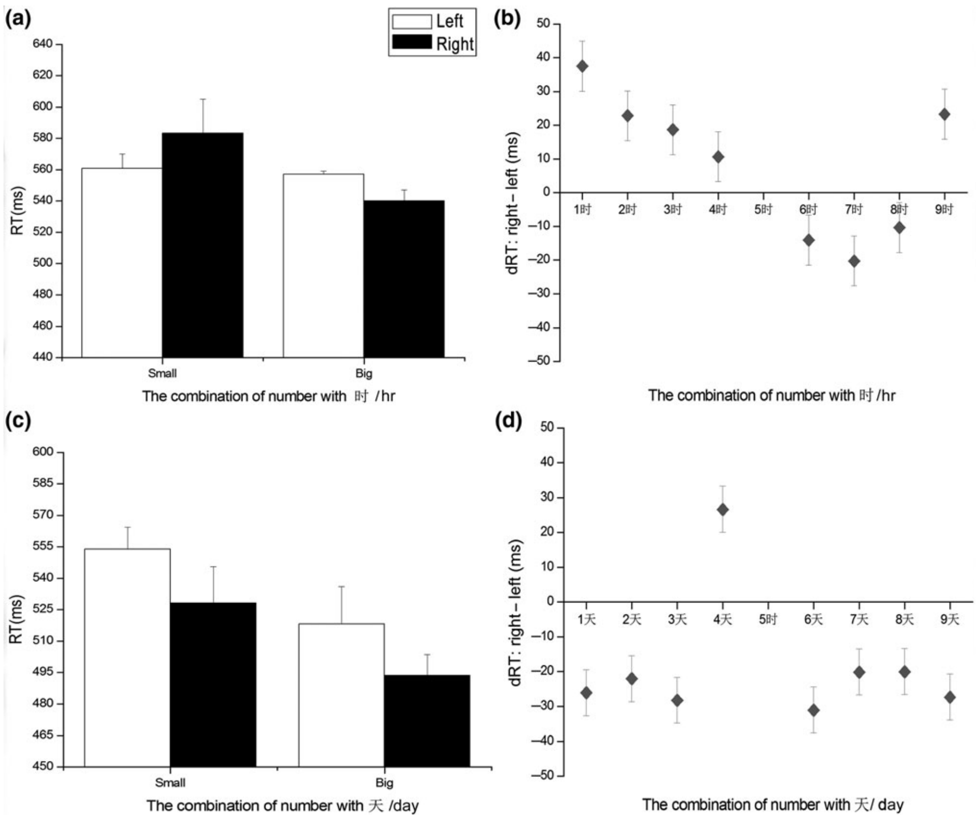

Figure 4. Mean reaction time for stimulus in each condition of Experiment 2b. Difference scores for reaction times (dRT) for stimulus pairs in each condition of Experiment 2b. (A) shows the mean reaction time to the comparison stimuli were numbers suffixed with 时(shí/hour); (B) represents the dRT result of the comparison stimuli. (C) represents the mean reaction time results to the comparison stimuli were numbers suffixed with 天(tiān/day); (D) represents the dRT result of the comparison stimuli. The error bars indicate standard errors of measurement.

which numbers were suffixed with different time units (1天tiān/day - 5时shí/hour - 9天), all the comparison stimuli were reacted to faster with the right hand. In Experiment 2b (in which the comparison stimuli varied from 1天/day to 9天/days), there was no significant difference between the left and right responses for 1分(fēn/minute) - 4分, $t(107) = -1.07$, $p = .29$, or for 1秒/second - 4秒, $t(107) = -0.86$, $p = .08$. Although the differences were not significant, the negative t-value suggested that left-hand responses were faster than right-hand responses. Furthermore, there was a lack of magnitude range (e.g., 6分/minutes - 9分/minutes) for those additional stimuli (1分/minutes - 4分/minutes), which may cause the disappearance of the STEARC effect for 1分/minutes - 4分/minutes. It has been shown that the SNARC effect is flexible: When the spatial frame of reference is different, the same number can be linked with either the left or the right side of the space, depending on whether it is the smallest or the largest in used range of numbers (Bächtold *et al.*, 1998; Dehaene *et al.*, 1993; Galfano, Rusconi, & Umiltà, 2006; Ristic *et al.*, 2006; Vuilleumier *et al.*, 2004). Finally, writing and reading order conventions did not influence the SNARC effect of number, which was suffixed with a different time unit. These results also indicated that the SNARC effect of number was not always stable when it was suffixed with concrete information.

EXPERIMENT 3a

In Experiments 1 and 2, we observed that the SNARC effect was flexible when the number was suffixed with a time unit. The association of number with space was adjusted by the current context that number was presented in Experiment 3; we employed numbers (56–64) near the level of changing unit order (60) of the time unit 分(fēn/minute), where the standard stimuli were numbers 1 and 60 with 时(1时shí/hour & 60时shí/hour). Numbers in the comparison stimuli (56–64) were all larger than 1, but their associated time units were one order smaller (分fēn/minute). We predicted that if the SNARC effect is flexible, it should present for the standard 1时(shí/hour), while it should disappear when the standard stimulus was 60时shí/hour. In other words, the time unit should influence the flexibility of a number that it suffixes. The following experiment tested our prediction.

Method

Participants

In all, 30 undergraduate students (14 males and 16 females, mean age 20.5 years) participated in the experiment. All participants were right-handed, their native language was Chinese, and they all had good vision. When they finished the experiment, they were given 10 Yuan as compensation.

Materials and procedure

The comparison stimuli included numbers near the number 60 with the time unit 分fēn/minute (56分, 57分, 58分, 59分; 61分, 62分, 63分, 64分). The standard stimulus was 1时(shí/hour), which was equal to 60分(fēn/minute). Thus, the numbers in the comparison stimuli were much larger than 1, whereas their time units were smaller than the standard unit of 时(shí/hour). For this experiment, the same procedure as in earlier experiments was used, but the participants were asked to judge whether the stimuli were larger than 1 时(shí/hour). There were 240 stimuli in a block and 480 trials in the entire experiment. There were 16 practice trials before the formal experiment, and each stimulus was repeated 30 times in a block. A break of a few minutes was given to the participants after the completion of one block. The entire experiment took about 15 min to complete.

Results and Discussion

We used the previous method to analyse the data. The RTs of the stimuli 56 (fēn/minutes), 57分, 58分, 59分, 61分, 62分, 63分, and 64分 were 649, 639, 653, 654, 618, 613, 622, and 627 ms, respectively. The main effect of response side was not significant, $F(1, 29) = 0.58$, $p = .45$; the main effect of magnitude was significant, $F(1, 29) = 36.54$, $p < .0001$, $\eta_p^2 = .56$. A significant interaction effect between magnitude and response side was observed (Figure 5A), $F(1, 29) = 5.95$, $p < .05$, $\eta_p^2 = .17$. The figure of dRT for the number with 分/minute is shown in Figure 5B.

The results of this experiment showed that although all the numbers (56–64) in comparison stimuli were larger than 1 (i.e., the standard stimulus), responses were faster

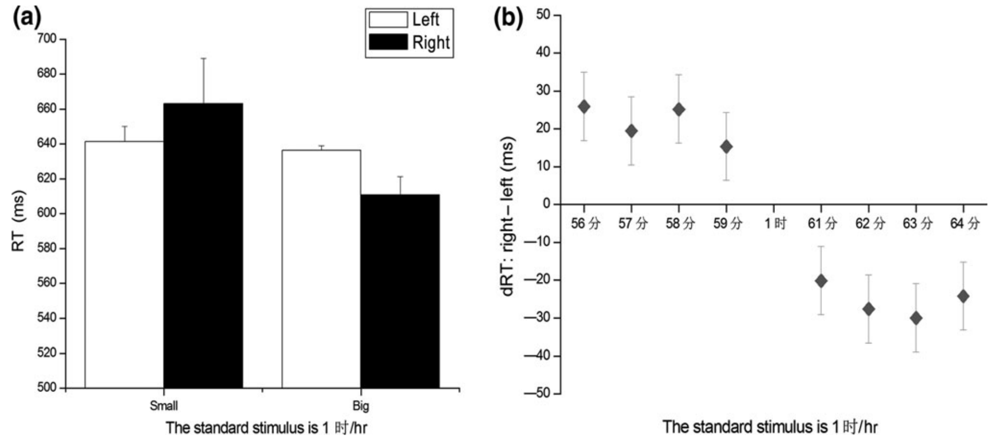

Figure 5. Mean reaction time for stimulus in Experiment 3a. Difference scores for reaction times (dRT) for stimulus pairs in Experiment 3a. (A) represents the mean reaction time results when the standard was 1时(shí/hour); (B) represents the dRT results. The error bars indicate standard errors of measurement.

for numbers 56–59 with time unit分(fēn/minute) when they were responded to with the left hand, whereas responses RT were shorter for numbers 61–64 with 分(fēn/minute) when they were responded to with the right hand. As the magnitude of 1时(shí/hour) was equivalent to 60分(fēn/minute), if the numbers (56–59) did not exceed the level of changing unit order (60) of time unit 分(fēn/minute), the subjects responded faster when the stimuli were responded to with the left hand, whereas if the numbers (61–64) exceeded the level of changing unit order (60), they responded faster when the stimuli were responded to with the right hand. The results indicated the flexibility for the STEARC effect and, more importantly, for the SNARC effect for a number which is near the level of changing unit order (60) of the time unit. There is alternative possibility that 1 hr was transformed into 60 min, so the comparison was likely taken place in 'minutes' with number 60. Based on the result of Experiment 3a, the threshold of time unit was important for SNARC effect of numbers which were near the unit. Experiment 3b further explored whether the number of standard stimulus was changed to number 60, the threshold of the time unit分(fēn/minute) in the standard stimulus, and whether time unit would still influence the SNARC effect of number or not.

EXPERIMENT 3b

Method

Participants

In all, 24 undergraduates participated in the experiment; their average age was 22.5 years. There were 10 males and 14 females, one of whom was left-handed. All the participants reported having normal or corrected-to-normal vision, and their native language was Chinese. All participants were paid 10 Yuan after the experiment.

Materials and procedure

The stimuli were 56分(fēn/minute), 57分, 58分, 59分, 61分, 62分, 63分, and 64分, and the stimuli 56天(tiān/day), 57天, 58天, 59天; 61时(shí/hour), 62时, 63时, and 64时 were used to balance the number of button presses. The standard stimulus was 60时(shí/hours). Although the numbers were near the level of changing unit order (60), the time units differed between the standard stimulus and the comparison stimuli. The procedure was the same as in the previous experiments. There were 480 trials in a block and 960 trials in the entire experiment. There were 32 practice trials before the formal experiment, and each stimulus was repeated 30 times in the experiment. The entire experiment took about 15 min to complete.

Results and Discussion

The same method was used to analyse the data. The RTs of the stimuli 56分(fēn/minutes), 57分, 58分, 59分; 61分, 62分, 63分, and 64分were 522, 530, 496, 526; 509, 499, 534, and 507, respectively. The main effect of response side was significant, $F(1, 23) = 4.9$, $p < .05$, $\eta_p^2 = .18$, and the main effect of number size was significant, $F(1, 23) = 4.53$, $p < .05$, $\eta_p^2 = .16$. The interaction effect between number magnitude and response side was not significant (Figure 6A), $F(1, 23) = 0.10$, $p = .76$, $\eta_p^2 = .004$. The figure of dRT result for the number with 分/minute is presented in Figure 6B. The difference was significant between the left response and the right response for the additional stimuli 61时/hours - 64时/hours, $t(95) = 2.23$, $p < .05$; for stimuli 56天/days - 59天/days, $t(95) = 4.23$, $p < .001$.

In Experiment 3b, the SNARC effect was not present. Responses to all stimuli were faster when they were responded to with the left hand. Chinese writing and reading conventions did not influence the orientation of the SNARC effect. Although the numbers alone were near the level of changing unit order (60), the combined magnitude with the time unit 时(shí/hour) in the standard was larger than all the comparison stimuli using the time unit 分(fēn/minute), and thus, all comparison stimuli were responded to faster on the left side. These results suggest that the SNARC effect is flexible, in that it changed when the suffixed time unit was changed.

In the experiments, additional stimuli (61时/hours - 64时/hours, 56天/days - 59天/days) were used to balance the number of button presses. We further analysed the SNARC effect

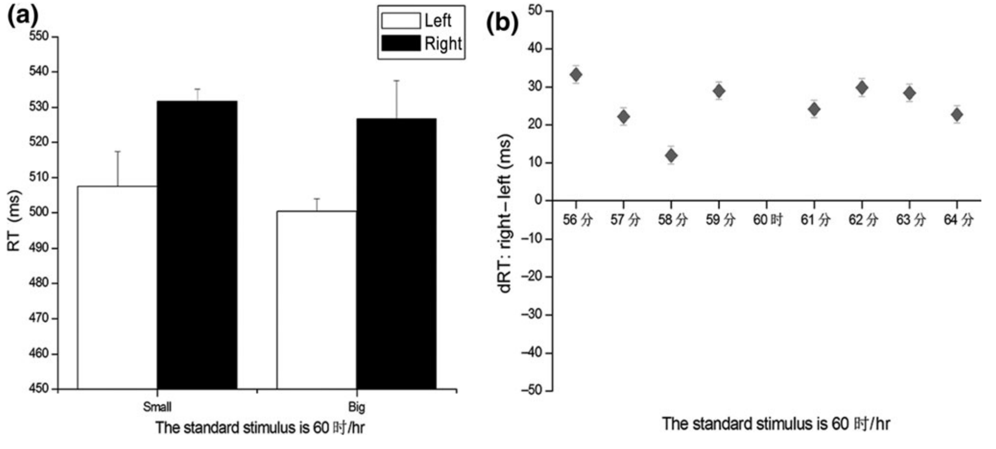

Figure 6. Mean reaction time for stimulus in Experiment 3b. Difference scores for reaction times (dRT) for stimulus pairs in Experiment 3b. (A) represents the mean reaction time result when the standard was 60时(shí/hour); (B) represents the dRT result. The error bars indicate standard errors of measurement.

of those stimuli and found the SNARC effect reemerged in this experiment; the additional stimuli were responded faster on the right side. However, there was no SNARC effect for these stimuli in Experiment 2b in which the additional stimuli were 1分/minute to 4分/minutes; 1秒/second to 4秒/seconds. It is known that comparing numbers close to the standard (i.e., 4 or 6) leads to relatively slow reaction time in comparing with numbers far from the standard (i.e., 1 or 9, Moyer & Landauer, 1967). This suggests the process of number magnitude close to the standard needs more cognition resources (Gevers *et al.*, 2006). As the SNARC effect would be stronger when number magnitude is processed more intensively, the SNARC effect would be larger when number magnitude is close to the standard (Gevers *et al.*, 2006). The additional stimuli 61时/hours - 64时/hours are close to the standard 60时/hours, and the SNARC effect thus appears. And the stimuli 56天/days - 59天/days are far larger than the standard 60时/hours; it is easy to categorize the relationship between the magnitude and the mental space. Therefore, the SNARC effect appears in additional stimuli in Experiment 3b, while it disappears in Experiment 2b in which the additional stimuli were 1分/minute to 4分/minutes, 1秒/second to 4秒/seconds.

Across Experiments 2 and 3, the SNARC effect followed different patterns when number was suffixed with time unit. In Experiment 2a (7 s – 1 year, the standard stimulus was 4 days), a reversed SNARC effect appeared. The standard SNARC effect was only found in Experiments 2b (the compared stimuli were 1–9 hr; the standard stimulus was 5 hr) and 3a (the compared stimuli were 56–64 min; the standard stimulus was 1 hr) and was not present at all in Experiments 2b (the comparison stimuli were 1–9 days; the standard stimulus was 5 hr) and 3b (the compared stimuli were 56–64 min; the standard stimulus was 60 hr). We separately analysed the difference in the overall reaction time between Experiment 2a and each of Experiments 1b, 2b, 3a, and 3b to explore whether time unit or conversion (the combined magnitude of the number and time unit) caused the different patterns of SNARC effect (Figure 7).

We used the one-way ANOVA followed by Bonferroni's *post-hoc* tests, among five groups. The results showed that the reaction time differences were not significant when comparing Experiment 2a (7 s – 1 year; 4 days was the standard stimulus) with 1b (second - year; day was the standard stimulus) with 2b (1–9 days; 5 hr was the standard stimulus); with 3b (56–64 min; the standard stimulus was 60 hr); $p_s > .99$. The reaction time differences were significant between Experiments 2a and 2b (1–9 hr; 5 hr was the standard stimulus), and Experiments 2a and 3a (56–64 min; the standard stimulus was 1 hr); $p_s < .0001$. The result of paired-samples *t*-test showed that reaction times in Experiment 2a were shorter than those in Experiment 2b (1–9 hr; 5 hr was the standard stimulus), $t(26) = -4.18, p < .0001$; Experiments 2a and 3a, $t(26) = -10.28, p < .0001$. While the reaction time differences between Experiments 2a and 1b (second - year; day was the standard stimulus) were not significant, $t(26) = .07, p = .94$; Experiments 2a and 2b (1–9 days; 5 hr was the standard stimulus), $t(26) = -1.07$, $p = .30$; Experiments 2a and 3b (56–64 min; 60 hr was the standard stimulus), $t(24) = .09, p = .93$.

According to the results of Experiments 1b, 2, and 3, the STEARC effect was present in Experiments 1b (second - year; day was the standard stimulus), 2a (7 s – 1 year; 4 days was the standard stimulus), 2b (1–9 hr; 5 hr was the standard stimulus), and 3a (56–64 min; the standard stimulus was 1 hr). However, it disappeared in Experiments 2b and 3b (56–64 min; the standard stimulus was 60 hr). On the one hand, it is showed that when comparing Experiment 2a with Experiment 2b, with Experiment 3a, the reaction time may be longer if the time unit and number were considered during task performance; on the other hand, the reaction time difference was not significant when comparing Experiment 2a (7 s – 1 year; 4 days was the standard stimulus) and Experiment 1b

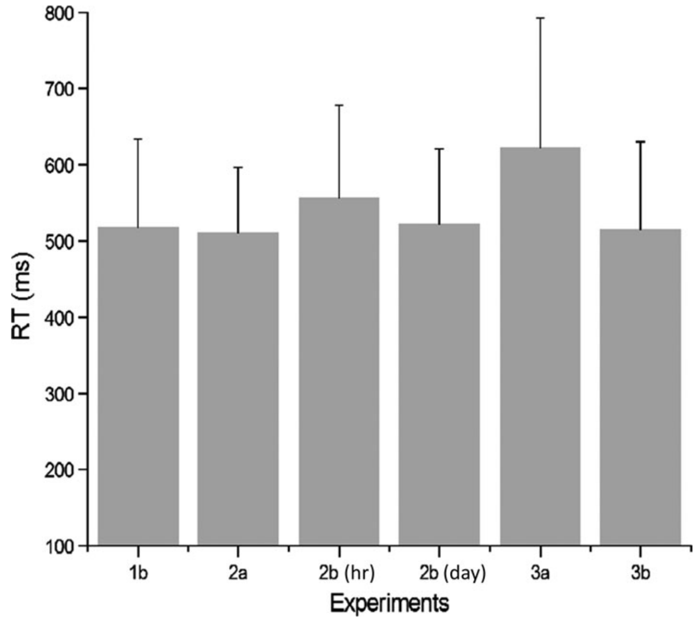

Figure 7. The mean reaction times of Experiments 1b, 2a, 2b (h), 2b (d), 3a, 3b. The error bars indicate standard errors of measurement.

(second - year; day was the standard stimulus). Besides, the patterns of the STEARC effect were similar in Experiments 1b and 2a. In summary, the results suggest that the time unit may dominate over the SNARC effect in Experiment 2a, and the converting process (i.e., integrating numbers and time units) may occur only when it is necessary (e.g., in a close comparison). The results indicate that the SNARC effect of the number is flexible when the number combines with the time unit, and the suffixed information has an effect on the flexibility of the SNARC effect.

Discussion

In this study, we used Arabic numbers combined with Chinese time units as experimental materials and the magnitude comparison task as a research paradigm; the results indicated that the SNARC effect was flexible when numbers were suffixed with time units, which means that the association between numbers and space is influenced by the suffixed magnitude information. Although both numbers and time units individually showed an association between stimulus magnitude and response side (Experiment 1), when a number was suffixed with a time unit, the SNARC effect was influenced by the time unit (Experiment 2 and Experiment 3).

A reverse SNARC effect appeared when the stimuli were 7秒(miǎo/second) to 1年(nián/year) (Experiment 2a). Experiment 2b also suggested that when numbers were suffixed with the same unit (1时shí/hour - 5时- 9时) or different units (1天tiān/day - 5时shí/hour - 9天), the SNARC effect of number was only presented on the same unit. This phenomenon was also found in the condition of numbers near the level of changing unit order (60, in Experiment 3). When the numbers 56–64 were suffixed with the same time unit时(shí/hour), the SNARC effect of the number was only present in Experiment 3a when the standard stimulus was 1时(shí/hour), while it was absent in Experiment 3b when the standard stimulus was 60时(shí/hour).

Conventional reading and writing order for time units seemed not to influence the orientation of SNARC effect in the present study. The findings from the present study do not preclude the theory that culture can influence the flexibility of SNARC effect. Our findings do show, however, that the magnitude information was more important in determining the orientation of SNARC effect. Consequently, we argue that the suffixed time unit was mainly responsible for the different spatial numerical association conditions in Experiments 2 and 3.

These findings cannot simply be attributed to the assumption of an automatic obligatory spatial representation of numbers or time unit along a mental number line or mental time line, which causes people to rank small numbers on the left visual field and large numbers on the right visual field. Dehaene referred to this mental number line and suggested that the direction of it reflected the influence of spatial information on number processing (Dehaene *et al.*, 1993; Hubbard, Piazza, Pinel, & Dehaene, 2005; Priftis, Zorzi, Meneghello, Marenzi, & Umiltà, 2006; Wood *et al.*, 2005). The mental time line is typically described as a left-short versus right-long association between time duration and space (Conson, Cinque, Barbarulo, & Trojano, 2008; Di Bono *et al.*, 2012; Ishihara *et al.*, 2008; Magnani, Oliveri, Mancuso, Galante, & Frassinetti, 2011; Oliveri *et al.*, 2009; Santiago, Lupiáñez, Pérez, & Funes, 2007; Santiago, Román, Ouellet, Rodríguez, & Pérez-Azor, 2010; Vallesi *et al.*, 2008, 2011; Weger & Pratt, 2008). However, some researchers disagreed with the idea of a mental number or time line (Crollen, Mahe, Collignon, & Seron, 2011; Fischer, 2006; Herrera, Macizo, & Semenza, 2008; Lindemann *et al.*, 2008; Masson, Pesenti, & Dormal, 2016; Oliveri *et al.*, 2008; Van Dijck, Gevers, & Fias, 2009). These authors have argued that the mental number line or mental time line implies that spatial numerical associations or spatial time associations are driven by an automatic activation; however, the left-to-right orientation of the mental number line sometimes is not obligatory and can be easily adapted or inhibited if the current task requires conceiving numbers differently (Bächtold *et al.*, 1998; Galfano *et al.*, 2006; Ristic *et al.*, 2006; Vuilleumier *et al.*, 2004).

The automatic SNARC effect or STEARC effect implies that spatial codes of number or time are immune against the influence of any other task or magnitude information concurrently executed. Based on the different association of numbers with space in Experiments 2 and 3, the magnitude information of number and time unit seemed to be processed in different ways. With the present material, we now provide a direct behavioural test of this prediction and demonstrate for the first time that SNARC effects of number are strongly influenced by the suffixed magnitude information. As previous studies showed that the SNARC effect of number was flexible (Bächtold *et al.*, 1998; Dehaene *et al.*, 1993; Fias, 1996; Gevers & Lammertyn, 2005; Guilherme, Klaus, Hans-Christoph, & Fischer, 2008; Ristic *et al.*, 2006; Rusconi *et al.*, 2006; Vuilleumier *et al.*, 2004), we further explored that the orientation of this effect would be adjusted when number was combined with a time unit, which means that the context may modulate the SNARC effect.

Previous studies have suggested that the magnitude of Arabic numbers affects time processing, such as duration estimations (Keus, Jenks, & Schwarz, 2005; Müller & Schwarz, 2008; Oliveri *et al.*, 2008; Vicario *et al.*, 2008; Xuan, Chen, He, & Zhang, 2009). Few studies have focused on the effect of background information on number processing (Badets, Andres, Di Luca, & Pesenti, 2007; Besner & Coltheart, 1979; Dehaene, 1992; Gabay, Leibovich, Henik, & Gronau, 2013; Henik & Tzelgov, 1982; Lu *et al.*, 2009; Schwarz & Heinze, 1998; Tzelgov, Meyer, & Henik, 1992). In this research, we found the impact of time unit on the number–space association when a number was suffixed with a time unit. The effect of time magnitude on the SNARC effect should not be attributed solely to the mathematical difference between numbers. The mathematical magnitude differences (1–9) were the same in 1b and Experiment 2, whereas the SNARC effects differed. Likewise, the numerical conditions were the same in Experiments 3a and 3b. Some researchers may argue that the distance effect was different across three experiments, which may influence the size of SNARC effect in these experiments (Chen & Verguts, 2010). Slowest latencies are the numbers that are closest to the standard (e.g., distance effect): The latencies to the numbers 4 and 6 will be longer than to the numbers 3 and 7. This factor was considered in this study; thus, we only compare the SNARC effect of number in the same types of time unit (Experiment 2a, Experiment 2b, and Experiment 3a vs. Experiment 3b). Therefore, it seemed that we perceived the mental magnitude of a number in different contexts to ensure that the same string numbers (1–9; 56–64) may be interpreted as distinctive. How the numbers were perceived to differ from each other in magnitude in specific contexts was important. It was perceived as the large magnitude in one condition (e.g., 1 year in Experiment 1a), but as the small magnitude in another condition (1 hr in Experiment 2a).

Our report that the spatial association of numbers is affected by a suffixed time unit substantially extends previous research showing that the SNARC effect can be adjusted by the frame of reference (Bächtold *et al.*, 1998; Ristic *et al.*, 2006; Rusconi *et al.*, 2006; Vuilleumier *et al.*, 2004) and contextual task-related information (Dehaene *et al.*, 1993). The research is consistent with Walsh's (2003) theory, which suggests that a common magnitude system that serves as a foundation for all types of mental representations that have magnitude as a dimension. The magnitude can be automatically activated through input from various magnitude dimensions, and this activation can combine and interfere with magnitude judgements in another dimension (Burr *et al.*, 2010; Cantlon, Platt, & Brannon, 2009; Oliveri *et al.*, 2008). Besides our findings, non-numerical information can be divided into non-numerical magnitude information (e.g., time units, weight units, and length units) and non-numerical order information (e.g., months of the year and letters of the alphabet). In a recent study, Prpic *et al.* (2016) dissociated these two types of information using musical symbols related to time duration and found that they were associated with different processing mechanisms. Additional studies are needed to explore how magnitude and order information are combined and processed from various perspectives using different materials and methods.

Conclusion

Taken together, our three experiments point to an intriguing property of the SNARC effect when numbers are suffixed with time units: The SNARC effect is sensitive to the magnitude of the time unit. We demonstrated that the SNARC effect is not obligatory and can be easily adapted or inhibited based on the current context. This finding adds to a growing body of literature on the flexibility of the SNARC effect. Moreover, our findings demonstrate that a common magnitude representation may exist across number, time, and space.

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