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Development of spatial representation of numbers: A study of the SNARC effect in Chinese children

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A B S T R A C T

Using the standard parity judgment task, this study investigated the development of numerical–spatial representation. Participants were 314 healthy right-handed Chinese children (from kindergarteners to sixth graders) and adults. The results revealed that all age groups showed a significant (or marginally significant in the case of first graders) SNARC (spatial–numerical association of response codes) effect, indicating that Chinese children as young as kindergarteners already had developed automatic spatial representations of numbers (or the mental number line). Surprisingly, however, the size of the SNARC effect did not show much developmental change. These results are discussed in the context of the literature on spatial representations of numbers and on cross-cultural differences in early development of number cognition.

Introduction

Systematic research over the last century has demonstrated a close relation between numbers and space (Dehaene, Bossini, & Giraux, 1993; Galton, 1880a, 1880b; Smith, 1964). One of the important findings during the past two decades is the SNARC (spatial–numerical association of response codes) effect, which refers to the finding that numbers are associated with left–right response coordinates

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(Dehaene et al., 1993). Using a typical parity judgment task (i.e., judging whether a number is odd or even), researchers have found that the left hand has an advantage in reaction times over the right hand when responding to small numbers, whereas the right hand has an advantage when responding to large numbers (Dehaene et al., 1993). The SNARC effect has been replicated in a wide variety of experimental settings with different numerical materials such as single digits, two-digit numbers, negative numbers, number words (e.g., one, two, three), numbers in different languages (e.g., Chinese, English, French), dot patterns, counting fingers, and auditory or tactile magnitude information (Berch, Foley, Hill, & Ryan, 1999; Fias, 1996; Fischer & Rottmann, 2005; Gevers & Lammertyn, 2005; Shaki, Fischer, & Petrusic, 2009; Zhou, Chen, Chen, & Dong, 2008).

Research has also shown that the SNARC effect is dependent on cultural and experiential factors. For example, Dehaene and colleagues (1993) found that Arabic readers, who read from right to left, showed a reversed SNARC effect. Furthermore, the reversed SNARC effect was weakened in Arabic readers who learned English as a second language (and hence learned to read from left to right). Interestingly, in a study of Chinese readers in Taiwan (Hung, Hung, Tzeng, & Wu, 2008), the direction of the SNARC effect varied within the same participants, depending on the writing system used in the task; Arabic numbers were mentally aligned with a horizontal left-to-right direction, whereas Chinese number words were aligned vertically with a top-to-bottom direction. The different orientations are due to the dominant context in which the numerical materials are often encountered because in Taiwan Arabic numbers are printed left to right, but Chinese number words are sometimes printed top to bottom. In sum, cultural factors such as the layout of printed words and daily experience with numbers may influence the SNARC effect.

Development of the SNARC effect

Although the SNARC effect has been consistently demonstrated among adults, little is known about its onset and early development. In their meta-analysis, Wood, Willmes, Nuerk, and Fischer (2008) found 108 empirical experiments of the SNARC effect with participants ranging in age from 9 to 66 years. Based on a subset ($n = 17$) of these experiments, they concluded that the SNARC effect increased with age from childhood to elderly age. Wood and colleagues' review did not include any earlier age groups, perhaps because Berch and colleagues' (1999) original study of the SNARC effect among young children showed that the SNARC effect did not emerge until Grade 3 (mean age = 9.2 years; but see Schweiter, Weinhold Zulauf, & von Aster, 2005, for evidence that one third of second graders in Switzerland showed the SNARC effect). Since Wood and colleagues' (2008) meta-analysis, however, there is more evidence of an earlier onset of the SNARC effect. Van Galen and Reitsma (2008) tested 7-, 8-, and 9-year-olds (corresponding to first, second, and third graders) and adults in The Netherlands with two different tasks: a magnitude judgment task (in which number magnitude is essential) and a gray box detection task (in which number magnitude is irrelevant because participants were asked to respond to the box on the right or the left of the number that may turn gray). Results showed that the SNARC effect was evident in all age groups for the magnitude judgment task, but it did not appear until third grade for the gray box detection task. These results suggest that the onset of the SNARC effect depends on whether numerical magnitude information is explicitly processed. When it is not explicitly processed, as in the gray box detection task in van Galen and Reitsma (2008) and the parity judgment task in Berch and colleagues (1999) and Schweiter and colleagues (2005), the SNARC effect does not appear until 8 or 9 years of age. When numerical magnitude is explicitly processed, the SNARC effect appears earlier (7 years of age in van Galen & Reitsma, 2008).

Although there is only limited research on the early development of the SNARC effect, several previous studies explored early foundations of the association between numbers and space. Opfer and Furlong (2011) and Opfer, Thompson, and Furlong (2010) found that, in a spatial search task, 4-year-olds showed a bias toward left-to-right orientation. It is plausible that this bias might be extended to numerical representation. Moreover, de Hevia and Spelke (2010) showed that even preverbal infants transferred the discrimination of an ordered series of numerosities to the discrimination of an ordered series of line lengths, suggesting an early predisposition to a correspondence between representations of numerical magnitude and spatial length. This result suggests an early development of spatial representation of non-symbolic numerical magnitude, which might serve as the basis for the development of spatial representation of symbolic numbers.

The current study

Given that young children have early predisposition for associating numbers/quantities with space and that cultural factors can affect the SNARC effect, it can be speculated that the SNARC effect may appear earlier than previously documented when studied among children who show an early advantage in number cognition. Chinese children have been found to have an advantage in number-related tasks such as digit span, counting, arithmetic, number estimates, and number Stroop tasks (Chen & Stevenson, 1988; Huntsinger, Jose, Liaw, & Ching, 1997; Miller, Kelly, & Zhou, 2005; Miller, Smith, Zhu, & Zhang, 1995; Stevenson, Chen, & Lee, 1993; Sy, Fang, & Huntsinger, 2003; Xu, Chen, Pan, & Li, 2013; Zhou et al., 2007). For example, Zhou and colleagues (2007) found that Chinese kindergarteners (mean age = 5.8 years) showed automatic processing of number magnitude based on a number Stroop task. This age of onset is earlier than that of children in other countries, for example, the end of the first grade (mean age = 7.32 years) in Israel (Rubinsten, Henik, Berger, & Shahar-Shalev, 2002), the third grade (mean age = 8.4 years) in Italy (Girelli, Lucangeli, & Butterworth, 2000), and the third grade (mean age = 9.2 years) in the United States (Berch et al., 1999).

In the current study, we used the standard parity judgment task (Dehaene et al., 1993) to examine the SNARC effect in eight age groups of Chinese participants: kindergarteners, first- through sixth-grade students, and adults. It should be noted that the SNARC effect obtained from the parity judgment task is likely to be based on automatic processing of magnitude because parity judgment does not involve explicit processing of magnitude information. Given the previous finding of Chinese children's early development of automatic processing of numbers (Zhou et al., 2007), we expected to find the automatic SNARC effect among the early age groups of our Chinese participants (i.e., kindergarten or first or second grade vs. third grade for American children [Berch et al., 1999] and Dutch children [van Galen & Reitsma, 2008]). We also expected that the size of the SNARC effect would increase with age, consistent with Wood and colleagues' (2008) meta-analysis.

Method

Participants

Participants were 314 healthy right-handed children (from kindergarteners to sixth graders) and adults. The children's handedness was assessed by asking both the teachers and the children themselves which hand the children used to hold chopsticks or a spoon for eating and a pen for writing. Children were recruited from two kindergartens and three primary schools in a middle-class neighborhood in Beijing, China. Adults were college students recruited from Beijing Normal University. Children were randomly selected from each class from kindergarten to sixth grade, but college students were recruited through flyers. All participants had normal or corrected-to-normal eyesight. Table 1 shows the distribution of participants by gender and age group and their mean age and age range.

Table 1
Basic information of participants by grade level.

Group	Number of participants			Age	
	Male	Female	Total	Mean age (years)	Age range (years)
Kindergarten	22	22	44	5.8	4.8–6.4
Grade 1	16	20	36	7.1	6.5–8.0
Grade 2	19	14	33	8.1	7.3–8.8
Grade 3	21	27	48	9.0	7.8–9.9
Grade 4	26	25	51	9.9	8.9–11.1
Grade 5	19	14	33	11.1	9.6–11.8
Grade 6	15	12	27	12.1	11.4–12.8
Adults	20	22	42	20.9	18.3–26.0

Experimental materials

Single-digit Arabic numerals from 1 to 9 were used for the parity judgment task. They were displayed one at a time (in Arial font size 48) in the center of the computer screen. The fixation was "*" of the same font size.

Procedure

Before the experiment, the experimenter explained the task to participants. To make sure that children understood the concept of parity, the experimenter asked them to name the odd and even numbers under 10. There are two sets of terms in Chinese for odd and even numbers. For kindergarteners and first graders, the odd and even numbers were expressed using the colloquial terms *dānshù* (single number literally) and *shuāngshù* (double number literally), which were taught in kindergarten. For other age groups, the formal terms *jīshù* (odd) and *ǒushù* (even) were used. Based on the screening questions, all participants understood the concept of parity. In addition, on the 10 practice trials, the mean correct rates were at least 90% for all age groups, including the youngest group.

At the start of the experiment, a fixation (*) was displayed in the center of the screen for 300 ms. After the fixation, the nine digits were displayed one at a time in a random order. Each digit stayed on the screen until the participant pressed the response key or 5000 ms had lapsed. There was a blank screen for 1000 ms before the next trial started. There were a total of 144 trials, with each digit repeated 16 times. These trials were grouped into two blocks; for one block participants pressed the left shift key for odd numbers and pressed the right shift key for even numbers, and the response keys were reversed for the other block. The order of the two blocks was counterbalanced across participants. Participants had a 1- to 3-min break between the two blocks. Before the formal experiment in each block, there were 10 practice trials. All participants were able to respond correctly on 9 or all 10 practice trials (<10% errors).

Results

Table 2 shows the mean reaction times (RTs) by response hand and number size for each age group. The grand mean error rate for all participants was 6.43%, with an average error rate of 7.8% for kindergarteners, 3.5% for first graders, 6.1% for second graders, 6.6% for third graders, 6.7% for fourth graders, 6.2% for fifth graders, 6.9% for sixth graders, and 4.9% for adults. Because of the low error rates and the overall consistency in their results with the RT data based on preliminary analyses, the results based on error rates are not included in the current article.

We used the two commonly used methods to examine the SNARC effect: (a) the analysis of variance (ANOVA) approach with the SNARC effect reflected in Response Hand × Number Size interaction

Table 2
Mean reaction times by grade level.

Group	Small number				Large number			
	Right hand		Left hand		Right hand		Left hand	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Kindergarten	1223	253	1166	221	1359	362	1375	340
Grade 1	1130	246	1123	237	1243	342	1280	340
Grade 2	961	204	947	197	986	267	1020	226
Grade 3	889	225	875	235	904	255	944	266
Grade 4	780	179	767	189	798	197	828	199
Grade5	659	117	643	99	670	123	690	122
Grade 6	600	119	583	104	602	115	621	121
Adults	535	74	521	70	536	76	552	78

Note: Values are reaction times (ms).

(Dehaene et al., 1993) and (b) the *t* test of regression coefficients of hand differences in RT over number magnitude (Fias & Fischer, 2005).

First, for each age group, a repeated-measures ANOVA was conducted with response hand (left vs. right) and number size (1–4 as "small" vs. 5–9 as "large") as within-participants factors. For all age groups, the main effect of number size was significant (see Table 3). Participants responded faster to smaller numbers than to larger ones. The main effect of response hand was not significant for any of the age groups.

Of most relevance to the current study, the interaction between number size and response hand was significant for all age groups (it was marginally significant for first graders) (see Table 3). An examination of the means showed evidence of the SNARC effect for all age groups; mean RTs were shorter when the left hand was used to respond to small numbers and the right hand was used to respond to large numbers than the other way around.

Second, we used the regression method proposed by Fias and Fischer (2005) to further investigate the SNARC effect. We first subtracted RTs of the left-hand responses from those of the right-hand responses and then regressed those differences on the magnitude of the numbers (1–9) and obtained a regression coefficient for each participant. With this method, the SNARC effect is shown as a negative regression coefficient; as the magnitude of the number increased from 1 to 9, the differences in RT between the right-hand and the left-hand responses changed from positive (faster for the left hand) to negative (faster for the right hand) (Fias, 1996; Fias & Fischer, 2005). Table 4 shows that a majority of participants in each age group (ranging from 64% for kindergarteners to 83% for adults) showed the SNARC effect. We then tested the significance of the mean regression coefficients (mean unstandardized *B*) of a given age group against zero using the one-sample *t* test. A significant *t* value suggests a significant SNARC effect. Results are shown in Table 5. The mean unstandardized coefficients ranged from −11.97 for kindergarteners to −6.07 for adults. As shown in Fig. 1, all age groups showed a significant SNARC effect except for first graders' marginal effect.

Table 3
Results of two-way ANOVA for each grade.

Effect	Group	*df*	*F*	*MSE*	*p*	η_p^2
Hand	Kindergarten	1	2.17	406.57	.148	.048
	Grade 1	1	1.94	241.94	.172	.053
	Grade 2	1	0.44	102.91	.513	.014
	Grade 3	1	1.23	154.29	.274	.025
	Grade 4	1	1.11	66.88	.298	.022
	Grade 5	1	0.12	5.68	.732	.004
	Grade 6	1	0.01	0.65	.915	.000
	Adults	1	0.08	1.48	.785	.002
Size	Kindergarten	1	37.95	16,284.16	.000	.469
	Grade 1	1	22.99	11,322.12	.000	.396
	Grade 2	1	5.26	2095.45	.029	.141
	Grade 3	1	7.02	1586.47	.011	.130
	Grade 4	1	26.45	1067.27	.000	.346
	Grade 5	1	18.48	530.23	.000	.366
	Grade 6	1	15.52	249.42	.001	.374
	Adults	1	27.23	160.33	.000	.399
Hand * Size	Kindergarten	1	4.62	1216.13	.037	.097
	Grade 1	1	3.57	442.65	.067	.093
	Grade 2	1	4.41	507.73	.044	.121
	Grade 3	1	4.23	671.73	.045	.083
	Grade 4	1	4.47	412.51	.039	.082
	Grade 5	1	7.16	266.44	.012	.183
	Grade 6	1	7.24	250.57	.012	.218
	Adults	1	17.79	144.59	.000	.303

Table 4
Number (and proportion) of individuals per age group who showed a non-zero SNARC effect.

Group	Number of individuals	Number (%) of individuals who showed SNARC effect < 0
Kindergarten	44	28 (63.6)
Grade 1	36	23 (63.9)
Grade 2	33	22 (66.7)
Grade 3	48	32 (66.7)
Grade 4	51	37 (72.5)
Grade 5	33	22 (66.7)
Grade 6	27	21 (77.8)
Adults	42	35 (83.3)

Table 5
Results of one-sample *t* test of slope for each grade.

	Kindergarten	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Adults
M	−11.97	−9.08	−10.51	−13.37	−6.41	−7.80	−7.70	−6.07
SD	36.78	28.92	21.12	32.48	23.81	12.92	11.91	9.27
t	−2.16*	−1.88$	−2.86**	−2.85**	−1.92$	−3.47**	−3.36**	−4.24**

Note: Values are *B* values.
* $p < .05$.
** $p < .01$.
$ Marginally significant, $p < .10$.

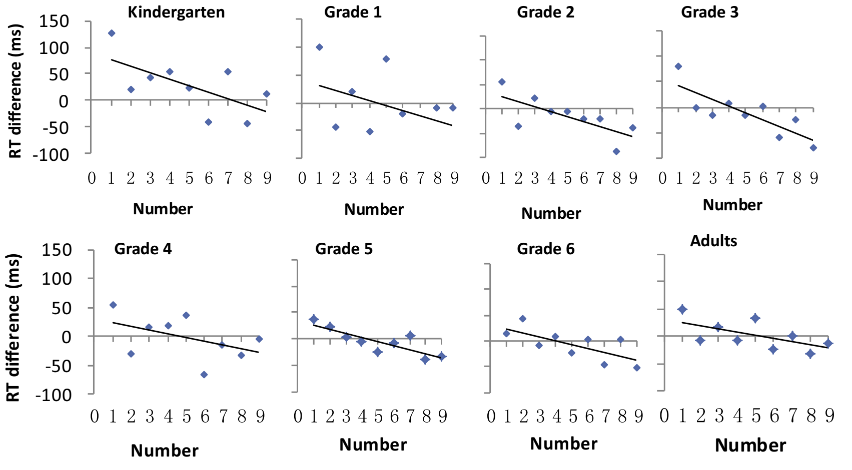

Fig. 1. The SNARC effect across grade levels. RT difference was calculated as RT for the right hand minus that for the left hand.

To understand age differences, we analyzed the data in two ways: (a) adding an age factor to the ANOVA approach to examine the three-way interaction (age by response hand by number size) and (b) correlating individual participants' unstandardized regression coefficients (*B*) with their age.

The three-way ANOVA showed that the main effects of number size and grade level were significant, $F(1,306) = 96.61$, $MSE = 12{,}343$, $p < .01$, $\eta_p^2 = .24$, and $F(7,306) = 69.50$, $MSE = 163{,}741$, $p < .01$, $\eta_p^2 = .61$, respectively. As mentioned earlier, participants responded faster to smaller numbers than to larger ones, and older participants responded faster than did younger participants. The main effect of response hand was not significant, $F(1,306) = 1.00$, $MSE = 4341$, $p = .32$, $\eta_p^2 = .00$. In terms of two-way interactions, the interaction between response hand and grade level was not significant,

$F(7,306) = 1.23$, $MSE = 4348$, $p = .29$, $\eta_p^2 = .03$, but that between number size and grade level was, $F(7,306) = 11.07$, $MSE = 12{,}306$, $p < .01$, $\eta_p^2 = .20$, showing a smaller effect for the middle grade levels than for the two extremes. As expected, the interaction between number size and response hand was significant, $F(1,306) = 29.42$, $MSE = 5134$, $p < .01$, $\eta_p^2 = .09$, suggesting a SNARC effect. Of most relevance to the age differences in the SNARC effect, we found that the three-way interaction was not significant, $F(7,306) = 0.38$, $MSE = 5126$, $p > .10$, $\eta_p^2 = .01$, suggesting no age differences in the SNARC effect. Confirming that finding, the correlation between individual participants' *B* and age was also not significant ($r = .068$, $p = .233$).

Discussion

The current study used the classic parity judgment task to investigate the development of numerical–spatial representations across eight age groups of Chinese participants from kindergarteners to adults. The results showed that overall error rates were very low, indicating that Chinese children as young as kindergarteners had a clear understanding of parity. Participants' RTs decreased significantly with age, reflecting participants' increasing efficiency in processing parity as well as overall cognitive processing and response speed (Kail, 1991, 1997). The processing speed also varied by the magnitude of the number, with smaller numbers having shorter RTs than larger numbers. This result is consistent with previous findings (Berch et al., 1999; Dehaene et al., 1993) indicating greater efficiency in processing smaller numbers.

One of the most important findings of the current study is that the SNARC effect was found in Chinese kindergarteners (mean age = 5.8 years). The left hand responded faster to small numbers than did the right hand, whereas the right hand responded faster to large numbers than did the left hand. This early onset of number–spatial representations was in clear contrast with that found for American children (Berch et al., 1999), Swiss children (Schweiter et al., 2005), and Dutch children (van Galen & Reitsma, 2008), who did not develop such automaticity of number–space associations until third grade based on the standard parity judgment task. This result confirmed an earlier finding of Chinese kindergarteners' automatic processing of number magnitude based on the number Stroop task (Zhou et al., 2007) and extended it to automatic numerical–spatial representations.

Zhou and colleagues (2007) suggested that earlier automatic magnitude processing found in Chinese children was probably due to earlier mathematical acquisition, which would also explain Chinese children's early emergence of the SNARC effect. First, children's numeric–spatial representations as shown by the SNARC effect are likely to be linked to their early mathematical learning. For example, Case and colleagues proposed that the mental number line provides a central conceptual structure for organizing a wide range of numerical knowledge (Case, 1992; Case & Okamoto, 1996; Griffin, Case, & Sandieson, 1992). Empirically, researchers have discovered that the quality of the linearity of numerical estimations (linked to the mental number line) is correlated with math skills such as simple addition (Booth & Siegler, 2008; Muldoon, Simms, Towse, Menzies, & Yue, 2011; Opfer et al., 2010). Specific to the SNARC effect, Schweiter and colleagues (2005) found that the SNARC effect was positively related to math performance for boys but was negatively related to math performance for girls. Most relevant to our sample, in a separate study of 40 Chinese third graders, we also found a significant positive correlation between the SNARC effect based on the parity task and math performance based on numerical processing tasks ($r = .411$, $p = .008$), including calculation, word problem solving, number reasoning, digit span, and magnitude estimation. On the other hand, other studies showed little or no associations between automatic number processing and mathematical skills (Bugden & Ansari, 2011; Schneider, Grabner, & Paetsch, 2009), perhaps due to differences in study design, age of participants, and indexes of automatic processing (e.g., the size congruity effect in Bugden & Ansari, 2011) and/or mathematical performance (e.g., achievement tests vs. self-reported grades in Schneider et al., 2009). More research is needed to understand the circumstances when the SNARC effect is or is not associated with mathematical performance.

Second, as mentioned in the Introduction, many previous studies showed that Chinese children have an advantage over their cross-cultural counterparts in several aspects of early numerical acquisition such as digit span, pronunciation duration, number-naming system, daily exposure to numbers, exposure to arithmetic concepts, parity, and early mathematical training at home and preschool (e.g., Chen & Stevenson, 1988; Ho & Fuson, 1998; Huntsinger et al., 1997; Kelly, Miller, Fang, & Feng, 1999; Miller et al., 1995, 2005; Siegler & Mu, 2008; Stigler, Lee, & Stevenson, 1986; Xu et al., 2013). In general, early preschoolers in China can already count and identify the numbers up to 10, and late preschoolers begin to learn about parity (the odd and even numbers were expressed as dānshù and shuāngshù) and simple arithmetic (Ministry of Education of the People's Republic of China, 2001; Ministry of Education of the People's Republic of China, 2012). In the United States, children learn about parity in Grade 2 (Berch et al., 1999). It should be noted that Muldoon and colleagues (2011) recently reported that Chinese children did not have an advantage in number representation as compared with Scottish children. However, their comparison was between 4.5-year-olds in China and 5.3-year-olds in Scotland because the authors wanted to find out whether Chinese children had an advantage in number representation when they were matched with Scottish children of the same (or even higher) math ability. It is likely that had Muldoon and colleagues used Scottish children of the same age as the Chinese, the results might have been different. In sum, the onset time of the SNARC effect appears to be different in different cultures, perhaps because of cultural and educational differences in early number learning such as an earlier emphasis on knowledge about numbers during the preschool and kindergarten years in China than in the United States and The Netherlands.

Of course, societies are constantly changing. For more than a decade, the U.S. government and the educational establishment have increased their emphasis on mathematics and science education, including early school years. Berch and colleagues' (1999) study was conducted more than a decade earlier, when American children's performance in international studies of mathematics was relatively poor. American children's performance in mathematics has improved gradually over the past decade (Mullis, Martin, & Foy, 2008). New research is needed to update Berch and colleagues' (1999) results about American children. International comparisons aside, the current study provides the first evidence of the SNARC effect among kindergarteners.

The other important finding of the current study concerns age similarities in the SNARC effect from kindergarteners to adults. Previously, Berch and colleagues (1999) found that the SNARC effect was attenuated at Grades 6 and 8. They believed that the SNARC effect was weakened with age because of the emergence of the MARC (markedness association of response code) effect at the higher grade levels. In contrast, Wood and colleagues' (2008) meta-analysis showed that the size of the SNARC effect increased with age. Using two different methods and a large sample, we found that the SNARC effect did not change significantly with age. These results contradict the conclusion in Wood and colleagues' meta-analytical study.

How can these inconsistencies be explained, and why did we not find age-related changes in the size of the SNARC effect? First, although Wood and colleagues (2008) included 108 independent experiments in their meta-analysis, only 17 were included in their analysis of age-related changes in the SNARC effect. Second, their analysis was based on mostly adult data (only two data points were from 9-year-olds; see Fig. 3 in Wood et al., 2008). Moreover, two data points from 40- and 50-year-olds appeared to be primarily responsible for their significant age effect, but these data points were driven mostly by patient samples. Third, because of the lack of the raw data, some of the average age estimates in their study were based on a large age range (i.e., a mean age of 22 years with a range of 18–64). In sum, either the age differences (a focus on children in our study and a focus on adults in their study) or methodological issues as outlined above might have accounted for the inconsistencies between our results and those of Wood and colleagues (2008).

How would we explain the lack of age-related change in children's and young adults' SNARC effect? One possible explanation is the dual processes of practice and inhibition. Wood and colleagues (2008) suggested that at least two cognitive factors may induce age-related variability in mental associations such as the SNARC effect: long-term practice (Brigman & Cherry, 2002; Knoch, Brugger, & Regard, 2005) and inhibition capacity (Zacks, 1989). Long-term practice may produce an age-related increase in the SNARC effect because the associations between numbers and space are strengthened by practice. On the other hand, inhibition capacity also increases with age (Comalli, Wapner, & Werner, 1962; Wright, Waterman, Prescott, & Murdoch-Eaton, 2003), which would help to reduce the size of the SNARC effect. These two processes may cancel each other out, resulting in a consistent SNARC effect. The involvement of the dual processes may also have accounted for the mixed findings regarding the associations between individual differences in the SNARC effect and mathematical performance. Future research should find ways to separate these two processes and examine how they can independently influence the SNARC effect.

Finally, it should be noted that, although the SNARC effect provides strong evidence for a close relationship between numbers and space (Dehaene, Dupoux, & Mehler, 1990; Dehaene et al., 1993) and the existence of the mental number line (a mental representation of numbers analogous to a physical number line), it may also involve non-visuospatial factors. Several recent studies have shown that verbal codes can affect the SNARC effect (Gevers et al., 2010; Proctor & Cho, 2006; van Dijck, Gevers, & Fias, 2009). For example, Van Dijck and colleagues (2009) found that the SNARC effect was eliminated by verbal working memory load during parity judgment but was eliminated by spatial working memory load during magnitude comparison. These results indicate that the spatial coding of numbers could have involved verbal representations. Future research on the SNARC effect should consider the involvement of verbal representations.

To summarize, the current study found that young Chinese children, including kindergarteners, already showed a clear pattern of automatic spatial representations of numbers (i.e., the SNARC effect) and that the size of the SNARC effect did not change with age. The early onset of the SNARC effect among Chinese children can be attributed to their early mathematical acquisition, and the lack of developmental changes in the SNARC effect may be due to competing processes, including practice and inhibition. These results add to the existing literature on early development of number cognition.

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