# Finding the spatial-numerical association of response codes (SNARC) in signed numbers: notational effects in accessing number representation

**Alessandro Chinello, PhD[a,b]**
**Maria Dolores de Hevia, PhD[c]**
**Carlo Geraci, PhD[d]**
**Luisa Girelli, PhD[b]**

[a] Center for Mind and Brain Sciences, University of Trento, Italy
[b] Department of Psychology, University of Milan Bicocca, Italy
[c] Department of Psychology, Harvard University, Cambridge, USA
[d] Institue Jean-Nicod, CNRS, Paris, France

Correspondence to: Luisa Girelli
University of Milano-Bicocca
Department of Psychology
Piazza dell'Ateneo Nuovo 1 - 20126 Milan, Italy
E-mail: luisa.girelli@unimib.it

**Summary**

**The present study investigates basic numerical processing in deaf signers and hearing individuals by evaluating notational effects (Arabic digits vs Italian sign language number signs) and response modality (manual vs pedal) in a parity judgment task. Overall, a standard SNARC effect emerged in both groups, suggesting similar numerical representation in hearing and deaf individuals. With the exception of Italian sign language stimuli in the hearing group, this effect applied to all stimuli notations and to both response modalities. In line with the special status of signs, the visuospatial complexity of finger configurations (i.e. number of extended fingers) affected the performance of the hearing group to a greater extent. Finally, the SNARC effect emerged systematically across lateralized effectors (manual/pedal response), challenging the hypothesis that the stimulus-response compatibility effect is specific to the effectors associated with the production of written and sign language. As for parity processing, both groups were similarly influenced by the parity information conveyed by the dominant hand, indicating the compositional nature of number signs irrespective of the preferred language modality.**

*KEY WORDS: deafness, LIS, sign language, signed number, SNARC*

## Introduction

Notation effects in number processing have long been investigated, exploiting the unique features of numbers that are due to their being represented in a variety of codes, including Arabic, verbal and visuo-analogical ones. The impact of these notations on internal numerical representation has been the focus of several targeted investigations leading to current models of numerical representation. An amodal internal numerical representation (1), as well as code-specific representations, including a visuospatial representation conceived as a mental number line, have been proposed (2).

The Triple Code Model of number processing postulates that numbers can be mentally represented on the basis of three different codes: visual, verbal and non-verbal quantity. Specifically, the semantic representation (quantity) has been conceptualized as an analogical and spatially organized continuum where numbers are represented as variable distributions of activation (2,3). The hypothesis of a spatial numerical representation is supported by observations of the Spatial-Numerical Association of Response Codes (SNARC) effect: when subjects are required to classify numbers, for instance in a parity judgment task, right-sided responses are faster for larger digits, whereas left-sided responses are faster for smaller digits (4-6). The SNARC effect has been observed for different numerical notations, as well as for different modalities of presentation (7) and, although it emerges even when the digit is irrelevant to the task (i.e. phoneme monitoring task; 5,6), its presence has been considered to constitute evidence of access to number magnitude information (but see 8). The SNARC effect reflects a typical interplay between numerical and spatial representations. This phenomenon suggests that the core representation of number is spatially organized as an oriented mental number line. The "spatial metaphor of numbers" is observable through the spatial biases reported in various cognitive tasks, which involve, among others, bisection lines flanked by numbers, shifts of visuospatial attention, and left-right visual stimuli detection (9,10). Additional support for number-space interaction comes from neuroanatomical data providing evidence of common neural substrates, partially overlapping in the parietal lobes, devoted to the processing of numbers and space (3). Critically, an acquired spatial and attentional deficit such as the one characterizing the neglect syndrome, may affect numerical performance suggesting that spatial representations may contribute to aspects of numerical processing (11).

Several studies highlighted that the SNARC effect may be an example of a spatial congruency between the response side in our egocentric space and the position of each numerical quantity on an oriented mental number line in the representational space (see 4,6,12, for contrasting results). Indeed, this stimulus-response compatibility effect seems to be more associated with the representational space than with the absolute magnitude. In fact, an inverse SNARC effect was obtained when subjects were asked to think of numbers as arranged on a clock face (13), supporting the hypothesis that the spatial arrangement of numbers may be modulated by contextual factors.

Moreover, some findings suggest that the spatial properties of the mental number line are influenced by cultural factors. In particular, the SNARC effect is modulated, even within the short term, by reading direction: not only were right-to-left readers found to exhibit a reduced (4, Experiment 7), or reversed (14) SNARC effect, but in Russian-Hebrew bilinguals, it was found that the direction of the SNARC effect could change within the same testing session depending on the language the participants were required to read (15).

A unique way of investigating the influence of the language system on the numerical spatial representation is to exploit the special features of sign languages, the natural languages used by deaf communities. Sign languages are characterized by a highly significant spatial component and, indeed, it is well known that deaf individuals, and in particular deaf signers, outperform hearing peers in some aspects of cognitive processing, such as speed of shifting visual attention and visual scanning (16,17), generation and manipulation of mental images (18), and visuospatial short-term memory (19). On these grounds, it is possible to assume that the primacy of visual cognition in deaf signers may influence numerical skills too (20,21) and, specifically, that the significant spatial components of sign language may impact on some visuospatial features of the mental number line.

In the last decade, a few studies have investigated standard behavioral signatures of the mental number line in deaf subjects who sign numbers by finger configurations. In particular, in a parity judgment task with number signs and Arabic digits, deaf signers exhibited a standard SNARC effect (22). This result suggests that deaf and hearing people share a common visuospatial numerical representation with increasing numbers organized from left to right (22-24). Yet, only one study directly compared deaf and hearing subjects (23) and, to our knowledge, none has so far compared processing of both Arabic and signed numbers in the two groups. The present study aims to further explore basic numerical processing in deaf and hearing individuals by evaluating notational effects (Arabic digits vs Italian sign language number signs) in a parity judgment task, using the SNARC effect as an index of access to visuospatial numerical representation.

Number signs are finger configurations that may well be processed by all subjects. However, there are factors specific to finger configurations, such as their compatibility with canonical counting strategies (25) and their association with one of the two hands, which are likely to influence their efficacy in accessing numerical representation (26,27). Italian deaf signers communicate using Italian sign language (*linguaggio italiano dei segni*, LIS), a natural language which is iconically transparent for digits from 1 to 10. Indeed, within this numerical range the numerosity of extended fingers mirrors the number's magnitude.

With regard to number signs, six different handshapes characterize the LIS number lexicon for the numbers from 0 to 5. Signs for numbers are generally produced from the thumb to the pinkie of the dominant hand (H1, i.e. the hand used to articulate one-handed signs in regular signing conversation), while numbers from 6 to 10 are signed using two hands. All two-handed number signs are combinations of the "five" handshape of the non-dominant hand (H2) plus one of the "one" to "five" signs of the dominant hand (H1; for details, see 22). Like hearing speakers, signers exhibit a prevalence of right-hand dominance with a relative preference to sign numbers up to 5 with the right hand and, for two-handed numbers (6 to 10), to sign the 5-handshape with the left hand. Accordingly, within this sign system, the more informative hand is the right dominant one (H1), whereas the non-dominant hand is useful for distinguishing signed numbers above or below 5. Interestingly, due to the strong visuospatial component of sign language articulation, the number sign system offers a unique opportunity to verify to what extent the orientation of the mental number line is influenced by the egocentric (signer's) or allocentric (sign reader's) perspectives. Indeed, in signed face-to-face communication the addressee (allocentrically) perceives a mirror image of what the sender produces (egocentric perspective, 22); typically, the addressee perceives signs (signed numbers, in our case) in the inverted visuospatial coordinates within the shared signing space (28). It is conceivable that both the egocentric and the allocentric frame of reference play a role in sign language, possibly by modulating the visuospatial representation of numbers. Recent evidence suggests that the orientation of the mental number line is not modulated by the signer's egocentric perspective, since a standard SNARC effect has been reported in German deaf signers (22).

To further explore the impact of the visuospatial features of sign language on the mental number line, in the present study LIS number signs were presented not only in the canonical hand assignment (i.e., using the right hand as dominant), but also in a mirrored assignment using the left hand as the dominant one. Thus, the two categories of LIS stimuli correspond to identical, although spatially inverted, hand configurations. Indeed, a recent study investigating numerical finger configurations in hearing subjects showed a more automatic access to numerosity from canonical finger configurations compared to non-canonical/atypical ones (29). Accordingly, we tested whether canonical and mirrored number signs have equal access to mental numerical representation in deaf signers.

Given deaf signers' advantages in various visual domains (i.e. visual attention and scanning, manipulation of mental images), primarily due to their experience with sign language, it is reasonable to suggest that their visuospatial representations might differ partially from those typically shown by their hearing counterparts (30). Some experience-based associations between numbers and hands have been identified in hearing participants: a study on finger counting showed a small number/right hand superiority effect that can be explained by the fact that, in daily-life activities, counting starts primarily with the right hand (25, but see 31). This can determine a strong association between small digits and the right hand and between both large and small digits and the left hand (see also, 32). Since the SNARC effect is culturally derived and largely influenced by the habitual reading direction, one may suggest that this stimulus-response compatibility is limited to, or maximized by the lateralized effectors directly recruited for communication purposes, i.e. the hands. The only study addressing this hypothesis, referred to as the ontogenetic view, reported a significant SNARC effect in both manual and pedal responses (33); these results contrast with the idea that the SNARC effect is limited to the effectors habitually linked to written language (i.e. the hands). However, the association between hands and language is even stronger in signers, not only for writing but also for face-to-face communication. Thus, deaf signers may represent an ideal sample for testing differences across effectors, and specifically for exploring the sensitivity of the effectors to the lateralized stimulus-response compatibility linked to the spatial orientation of the mental number line. Moreover, hearing participants represent an original control group, not yet tested in the processing of number signs. In the present study we compare manual and pedal responses in both hearing subjects and deaf signers performing a parity judgment task.

Numerical stimuli are presented in two numerical notations: signs and Arabic. While signs for numbers greater than 10 can be hard for hearing subjects to recognize, numbers from 0 to 10 are iconically transparent for both deaf and hearing participants (29).

Accordingly, we might expect the SNARC effect to emerge in signed numbers both in signers (22,24) and hearing subjects, similarly to what was found for other numerical notations, such as number words and dice patterns (34). However, it is likely that, due to differences in practice, hearing subjects are less efficient in processing number signs. In particular, the visuospatial features of signed numbers, such as the number of extended fingers and the hand dominance, may differently impact on the performance of the two groups. Therefore, we expect a different impact of two manipulated factors (the number of extended fingers and the degree of visual pattern familiarity) on the two groups respectively. First, we consider that hearing subjects, being less efficient (familiar) with number signs, should be more sensitive to their visual complexity, i.e., show a direct relation between speed of processing and/or accuracy and number of extended fingers. On the contrary, deaf subjects may process signed numbers as canonical visual patterns, showing a weaker sensitivity to the number of extended fingers or, at least, only a difference in performance between one-handed (i.e., 1 to 5) and two-handed number signs (i.e., 6 to 9). Second, in order to explore the familiarity effect in numerical visual pattern recognition, we manipulated the hand-dominance in the representation of signed numbers, comparing canonical (right-hand dominant) and mirrored configurations (left-hand dominant, see Fig. 1) in both groups. Since deaf participants, interacting with other signers, show a higher level of familiarization with number signs, we expect to see a weaker influence of the "mirror effect" (i.e. canonical vs mirrored patterns) during sign recognition in the deaf group. By contrast, the processing of signed numbers by hearing participants may be more dependent on spatial coordinates and hand dominance, while a further factor that can asymmetrically affect hearing and deaf participants' performance is related to the specific structure of signed numbers. As suggested by Zhang & Norman (35), signed numbers are characterized by a base-10, sub-base-5 system that can specifically influence the processing of parity information. In particular, two-handed signed numbers, such as the even number 6, are composed of two handshapes representing two odd numbers, such as 5 (H2) and 1 (H1). It has been reported that this incongruence affects signers' performance in a parity judgment task, favoring the hypothesis of a decomposed parity processing based on the dominant handshape (H1) rather than on holistic processing of whole-number parity (H1 and H2; 22). To address this issue, we considered the effect of numerical parity status on the response side: i.e., the linguistic markedness association of response codes (MARC) effect, which indicates an advantage in terms of reaction times (RTs) for congruent pairs among marked (left-odd) and unmarked (right-even) lexical entries as compared to incongruent pairs (i.e. left-even, 34).

So far, the few results available regarding the MARC effect on deaf signers favor a decomposed parity processing hypothesis. Indeed, the information of the dominant hand (H1) seems to be more important for the response than the whole-number sign composed of H1 and H2 in two-handed signs (22). However, less is known about the influence of the dominant hand (H1) for signed number parity retrieval in hearing participants.

To address these questions, the present study investigates the influence of language system and visual features of signs on numerical spatial representation, looking for the SNARC effect induced by the processing of Arabic numbers and LIS number signs in both deaf and hearing individuals.

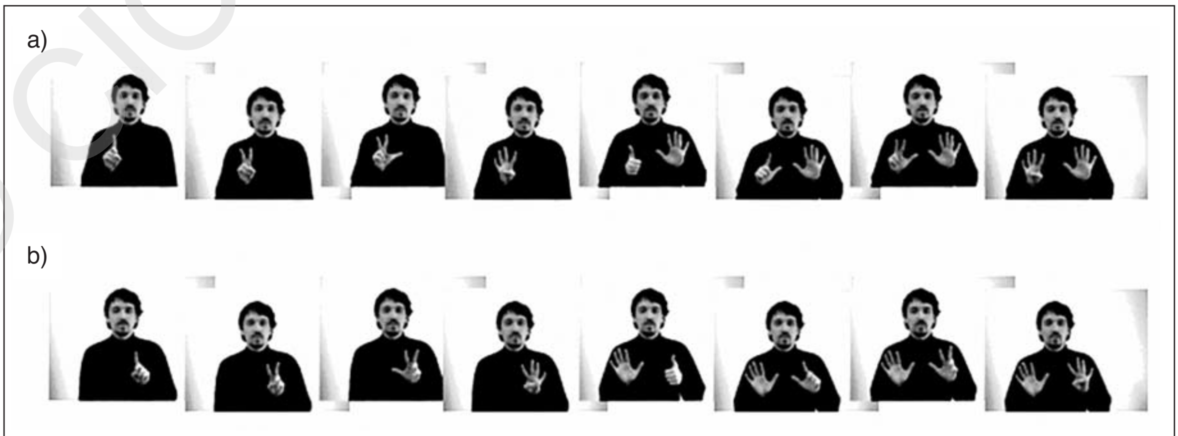


Figure 1 - Canonical (a) and mirrored (b) number signs in LIS.

All participants were either born deaf or became deaf before they could acquire any spoken Italian through simple exposure to the language. However, they were either native signers (born into a deaf family) or exposed to LIS from a very early age (before 6 years).

## Materials and methods

### *Participants*

Fifteen prelingually deaf signers (7 males, 8 females, mean age 31 years, range 18-40), and 20 hearing subjects (9 males, 11 females, mean age 30 years, range 22-42) participated in the study. The deaf subjects used LIS as their preferred language, while the hearing subjects were fully naïve to sign language. All participants were right-handed according to the Edinburgh Handedness Inventory (36), and reported normal or corrected-to-normal vision.

### *Stimuli*

The stimuli consisted of the numbers 1 to 9 (except 5); each number was presented 15 times, and the order of presentation was random. Numbers were presented in two different notations (one block per notation): Arabic and LIS. The LIS stimuli included canonical and mirrored configurations, as defined by the dominant hand used (Fig. 1). E-Prime software was used for stimuli presentation (37). Arabic numbers were printed in Times New Roman covering a visual angle of approximately 1° horizontally and 1.5° vertically, and LIS numbers were colored photos of a person signing the numbers, covering a visual angle of approximately 10.2° horizontally and 7.7° vertically at a viewing distance of approximately 50 cm.

### *Design and procedure*

Participants were required to classify numbers as even or odd and they responded either by pressing the right / left key-button using their hands (manual response) or the right / left pedal using their feet (pedal response).
The experiment consisted of 2 (Arabic/LIS) x 2 (manual/pedal response) blocks of 120 trials each, except for a LIS block of 240 trials (120 canonical + 120 mirrored stimuli) randomly presented in each session. The key assignment (odd-left/even-right and odd-right/even-left) was counterbalanced across participants and administered in two different sessions, at least 1 day apart (but within 14 days), for each subject. The order of the blocks was counterbalanced across participants. Overall, considering the two-task sessions, each participant was presented with 1440 experimental trials. Eight practice trials were performed at the beginning of the Arabic block, and sixteen practice trials at the beginning of the LIS block. The subjects sat at a distance of approximately 50 cm from the monitor. Each trial consisted of a fixation point (1000 ms) centered on a computer screen (1280x1024), followed by a central numerical stimulus which remained present until the subject's response.

## Results

Incorrect answers (hearing: 3.5%, deaf: 3.6%; Table 1) and reaction times (RTs) beyond ± 2 standard deviations (hearing 1.4%, deaf 1.7%) outside the group mean were not included in the analyses of the RTs.
With the aim of disentangling specific effects modulated by the group factor, the RTs of deaf and hearing participants were explored using an ANOVA (to this end, only results related to the group effect are reported).
We conducted a mixed 2x2x4x2x2 ANOVA with notation

Table 1 - Mean error rates (%) and mean response times for Arabic and Italian sign language (LIS) stimuli (divided by magnitude: smaller/greater than 5) and the responding effectors.

| Group | Effectors | Side | Arabic | | LIS | |
|---|---|---|---|---|---|---|
| | | | Smaller than 5 | Greater than 5 | Smaller than 5 | Greater than 5 |
| Deaf | Hands | L | 2.3<br>580 | 5.1<br>611 | 2.6<br>702 | 4.3<br>762 |
| | | R | 5.9<br>581 | 2.1<br>581 | 4.7<br>702 | 2.7<br>735 |
| | Feet | L | 4.1<br>654 | 4.6<br>676 | 2.9<br>768 | 4.2<br>818 |
| | | R | 3.6<br>667 | 2.4<br>667 | 3.2<br>757 | 3.1<br>793 |
| Hearing | Hands | L | 1.5<br>523 | 4.1<br>539 | 2.5<br>667 | 5.0<br>772 |
| | | R | 4.1<br>530 | 1.7<br>513 | 3.8<br>665 | 3.9<br>763 |
| | Feet | L | 3.1<br>558 | 4.0<br>571 | 2.5<br>701 | 4.8<br>792 |
| | | R | 3.8<br>555 | 1.8<br>547 | 2.7<br>696 | 4.0<br>774 |

(Arabic/LIS), effector (manual/pedal response), magnitude (bin 1: 1-2, bin 2: 3-4, bin 3: 6-7, bin 4: 8-9), response side (left/right) as within-subject factors, and group (deaf/hearing) as between-subjects factor. All the main effects were significant. Overall, the hearing participants were faster than their deaf counterparts (F(1,33)=8.89, p<.01). Responses for Arabic numbers were faster than for LIS numbers (F(1,33)=710.01, p<.001), reflecting different encoding times based on the complexity of stimuli notations. Manual responses were faster than pedal responses (F(1,33)=30.92, p<.001), and large numbers were responded to less rapidly than smaller ones (F(3,99)=100.31, p<.001). Finally, right-sided responses were faster than left-sided ones (F(1,33)=8.91, p<.01).

Interestingly, group interacted with the following factors: numerical notation (F(1,33)=22.31, p<.001), effector (F(1,33)=5.70, p<.05) and magnitude (F(1,33)=5.21, p<.01). Whereas the hearing participants responded faster when presented with Arabic digits, LIS stimuli elicited similar RTs in both groups. Deaf and hearing participants differed only in pedal responses and magnitude was found to modulate performance similarly in both groups, albeit more strongly in the hearing subjects (Fig. 2).

Notation interacted significantly with magnitude (F(3,99)=118.70, p<.001), albeit to a different extent in the two groups (F(3,99)=21.71, p<.001). Post-hoc tests (Bonferroni) revealed that the magnitude effect emerged mainly for LIS numbers in deaf subjects: bin 1 yielded faster responses than bin 2 (p<.05), and bin 3 yielded faster responses than bin 4 (p<.005). Similarly, in the hearing participants, the magnitude effect emerged only in LIS stimuli, but with RTs increasing linearly with magnitude (bin 1 vs bin 2 vs bin 3 vs bin 4, all comparisons, p<.001). In view of the significant interaction between group and dependent variables, all remaining analyses were performed separately for the two groups (hearing vs deaf participants) to obtain clearer results.

### *SNARC and MARC effects*

Respectively, for both notations (Arabic/LIS) and effectors (manual/pedal response), the right-side minus left-side mean RTs were entered into a multiple linear regression analysis using a repeated measures design with magnitude (1-2-3-4-6-7-8-9), parity (even/odd), and parity of the handshape of the dominant hand (H1 parity) as predictors (see 22,34,38).

In deaf subjects, a significant SNARC effect slope was obtained in the manual responses for both numerical notations: Arabic (t(14)=-3.09; p<.01), and LIS (t(14)=-2.27; p<.05) (Fig. 3, over). In the pedal responses, the SNARC effect slope was again significant although more marked for the LIS number signs (Arabic: t(14)=-1.94; p<.05 and LIS: t(14)=-2.20; p<.05).

The results from the hearing group (Fig. 4, over) confirmed the presence of a SNARC effect only for Arabic stimuli in both manual (t(19)=-3.97; p<.01) and pedal responses (t(19)=-2.62; p<.01), and no SNARC effect for LIS number signs, either in manual (t(19)=-.71; p=.25) or pedal responses (t(19)=-1.16; p=.13).

No MARC effect emerged in the processing of LIS stimuli (34), regardless of number notation and response modalities.

In accordance with Iversen et al. (22), we considered whether parity retrieval was affected by the sub-base 5 of the number sign system, using a repeated measures regression analysis. Deaf subjects exhibited a significant effect of H1 parity, more marked in pedal responses (t(14)=-3.41, p<.01) than in manual ones (t(14)=-1.72, p=.06), while in hearing participants, the H1 parity effect modulated only pedal responses (t(19)=2.53, p<.05). In both groups, results with Arabic digits did not reveal any influence of parity status (MARC or H1 parity effects) on performance.

### *LIS effect*

To investigate the effect of the canonical/mirrored configuration in LIS numbers, for each group, we conducted separate 2x2x2x2 ANOVAs with effector (manual/pedal response), number of hands used to sign ("one-handed": 1-2-3-4, "two-handed": 6-7-8-9), LIS (canonical/mirrored), and response side (right/left) as within-subjects factors (only interactions with LIS are reported).

Both groups showed a LIS x number of hands x side interaction (deaf: F(1,14)=6.35, p<.05; hearing: F(1,19)=15.09;

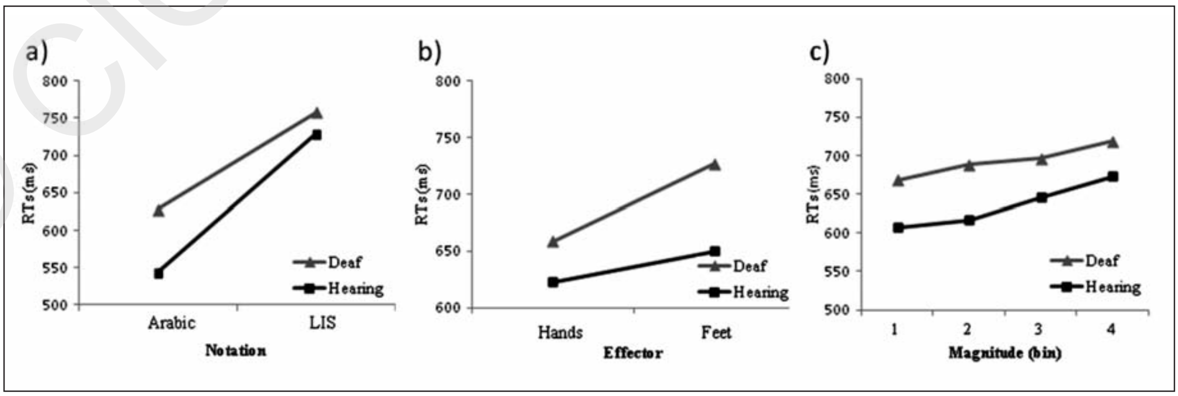


Figure 2 - Mean reaction times (RTs) for deaf and hearing participants are shown separately as a function of notation (a), effector (b), and numerical magnitude (c).

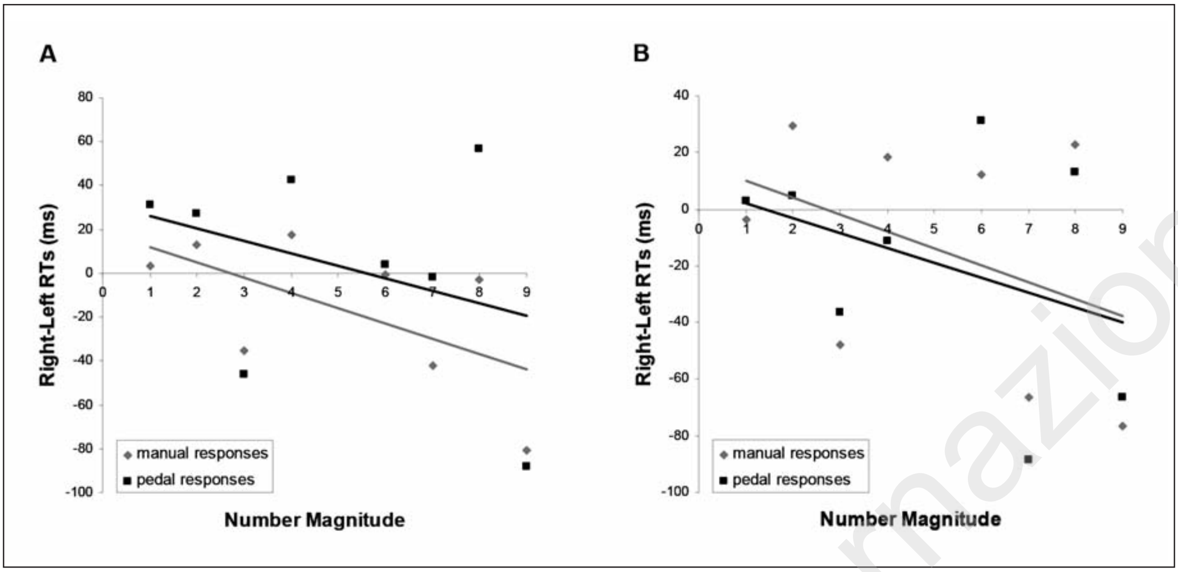


Figure 3 - Observed differences of right – left RTs for Arabic (A) and LIS (B) notations and linear regression of RT difference for the number presented in deaf subjects.

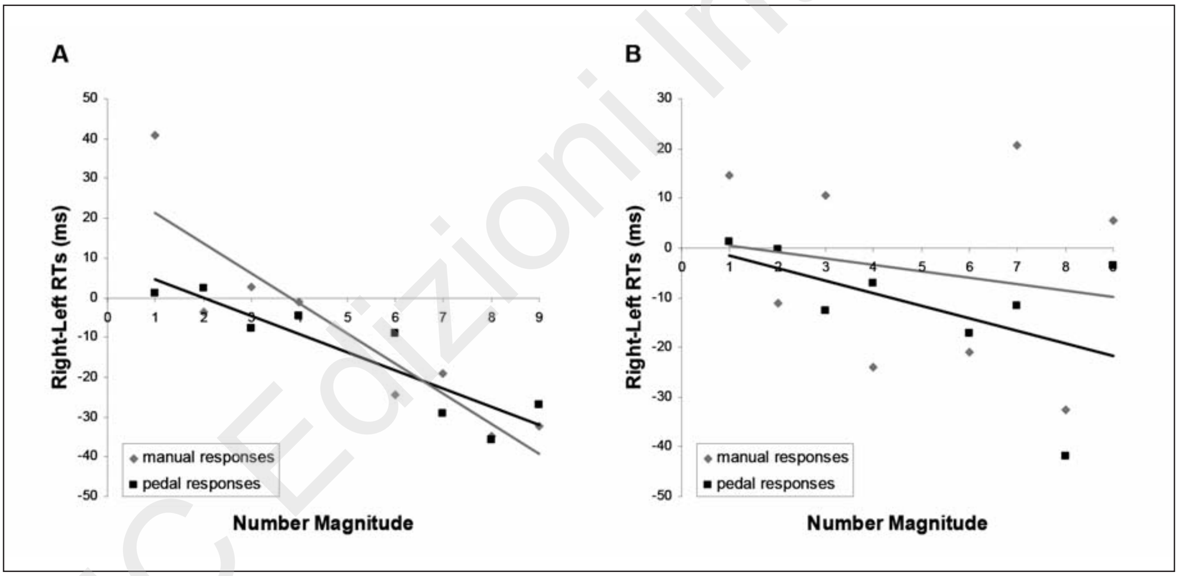


Figure 4 - Observed differences of right – left RTs for Arabic (A) and LIS (B) notations and linear regression of RT difference for the number presented in hearing subjects.



$p<.01$). Crucially, when one-handed numbers were displayed, a clear-cut advantage was observed for responding to left-sided stimuli with the left hand, and to right-sided stimuli with the right hand, reflecting a standard Simon effect (39). This effect indicates that detection of a lateralized stimulus is significantly faster when both its location and the location of the response are the same, as opposed to when the two locations differ, even when stimulus location is irrelevant to the task. For numbers signed with both hands, our data reflect a systematic advantage for right-sided responses, in line with the standard SNARC effect.

## Discussion

Overall, Arabic stimuli were easier than number signs for all subjects, regardless of the preferred language modality (signed vs spoken), most likely due to the limited visuoperceptual complexity of these stimuli compared with numerical finger configurations. Moreover, in the present study the notational effect was possibly increased by the fact that the Arabic code is thought to be the preferred entry code for extracting parity information (2). The visuoperceptual asymmetry across these stimuli notations is also reflected by the fact that the magnitude effect modulated the processing of LIS stimuli only, even though the extent of this modulation differed in the two groups. The performance of the deaf individuals was most markedly infuenced by the extreme values (bin 1 being the easiest and bin 4 being the most difficult condition), since in this group the transition from one- to two-handed number signs (i.e., bin 2 vs bin 3) did not impact significantly on the speed of processing. On the other hand, the hearing participants were most influenced by the visual complexity of finger configurations, as indicated by the continuous effect of magnitude on response latencies to LIS stimuli.

The overall advantage for manual responses well reflects the sensorimotor specialization of these effectors (33). Not surprisingly, the effector asymmetry tended to decrease as a function of the stimulus difficulty (i.e., magnitude, notation). Most interestingly, besides the strong association between hands and numbers (e.g., finger counting) and their role in language production, either written or signed, the SNARC effect emerged similarly in manual and pedal responses. In line with Schwarz and Müller (33), an effector-independent SNARC effect may indicate a phylogenetic origin of a spatially-oriented numerical representation. Alternatively, considering the weak ontogenetic view of this effect, the effector-independent SNARC effect may be the result of a generalization, to all effectors, of scanning direction determined by the dominant writing system, whether or not these effectors are involved in language processing.

It is worth noticing that the SNARC effect emerged in both the Arabic and the signed codes, although in hearing participants signed numbers were less efficient in yielding a SNARC effect. However, the SNARC effect was further modulated by the type of finger configurations: the processing of one-handed LIS numbers (small numbers) was faster in case of side congruency between signed number (left- or right-sided) and response key (left or right) for both groups. This means that for one-handed numbers the stimulus-response compatibility effect took the form of a standard Simon effect (39), while the number of hands x side interaction, shown by all the subjects in two-handed configurations, reflects an overall advantage for right-sided responses to two-handed signed numbers (i.e. 6 to 9), as expected from the hypothesis of a left-to-right oriented number line.

Interestingly, the influence of the dominant hand on LIS number signs, (canonical vs mirrored finger configurations) did not emerge in the performance of either the deaf or the hearing subjects. Thus, processing of number signs was not modulated by the specific visual perspective adopted, either the addressee's (canonical perspective) or the egocentric one (mirrored perspective). However, we cannot exclude that stronger stimulus-response compatibility associations, responsible for the observed Simon and SNARC effects, potentially masked the role of hand dominance in number signing.

The influence of notation on the SNARC effect emerged only in the hearing group, in which LIS stimuli did not yield an overall response compatibility effect. Consistently with a classical visuospatial interpretation of the SNARC effect, this result may mean that for hearing subjects number signs are less efficient for accessing magnitude information. Note that previous studies supporting the automatic processing of canonical finger configurations presented numbers as isolated finger patterns (29), whereas in this study the number signs were photographs of the upper half of a signer. It is possible that this methodological variation may underlie a critical difference in the processing of signed numbers and canonical finger numeral configurations. Moreover, the two groups showed a similar pattern of RTs for LIS processing; thus, the asymmetry in the emergence of the SNARC effect may not be attributable to differences in the speed of processing, but possibly to the fact that for hearing subjects number signs do not represent a language-related code, as they do for deaf signers. This result seems to conflict with with the presence of the SNARC effect across different notations, even in visual dice patterns (7). However, LIS number signs and dice patterns are clearly different in terms of visual complexity and of prototypicality as visual patterns. Accordingly, it is likely that they differ in their efficacy for accessing numerical meaning.

Recently an alternative interpretation attributed stimulus-response compatibility effects, such as the SNARC, to a linguistic phenomenon. Specifically, it was suggested that bipolar dimensions, such as small-large and odd-even, may undergo a verbally mediated spatial coding (+/-) and that corresponding polarities induce faster response selection in binary classification tasks (40,41). Within this framework, the aforementioned disparities in the SNARC effect between hearing and deaf participants would reflect the linguistic influence on the polarization effect, so that signed numbers would induce a polarity effect only in deaf participants.

Finally, with regard to the parity information, no MARC effect emerged for Arabic or LIS numbers. However, as suggested elsewhere (22), the sub-base-5 property of LIS numbers clearly affected processing of the parity of signed numbers. Our results indicate that the parity status of the dominant hand (H1) overcame the parity status of the whole-signed numbers, in particular in deaf performance and mainly pedal responses. Probably, pedal responses were more effortful, as reflected by longer RTs and lower accuracy, and thus more sensitive to contrasting information regarding the mismatch between the parity status of the dominant hand (H1) and the parity status of the whole signed number (respectively for one- or two-handed signs).

Indeed, the sub-base-5 property of LIS implies, as a potential problem, that the number of fingers on the dominant hand always has the opposite parity status to two-handed signed numbers. For instance, a one-handed finger configuration of "two" is associated with the even status, while the same configuration within a two-handed sign (i.e. "seven" = "five + two") is associated with the odd status of the whole number. Our results may suggest a compositional nature for parity retrieval in LIS, especially for two-handed signs where the sub-base-5 LIS numbers are not transcoded into a base-10 format before retrieving the parity status. Thus, LIS numbers might access parity information by using a language dependent (lexical) route, in which language-specific properties influence the odd/even decision. On the contrary, Arabic digits may do so by activating a number-specific access (semantic route) adopting a number-specific base-10 format. Since the pattern of results for LIS numbers differed from those for Arabic digits, our findings support a notation-dependent mechanism (lexical and semantic) for extracting parity information, as hypothesized by Iversen et al. (22). Quite surprisingly, even hearing participants exhibited a similar modulation of H1 parity on number processing. This result reflects the specific compositional structure of signed numbers shared by hearing and deaf populations during a parity judgment task irrespective of the preferential language (verbal vs signed), and level of familiarization with number signs.

In the present study both hearing and deaf individuals showed a SNARC effect suggesting that these populations share a common visuospatial representation of numbers. This effect emerged equally for manual and pedal responses, strengthening the view that the SNARC effect reflects the underlying abstract nature of spatial numerical representation, and is not entirely dependent on an overlearned sensorimotor association strictly linked to language production (33). Although hearing loss does not prevent the existence of an oriented mental number line, experience of sign language affects qualitatively the processing of number signs. Moreover, besides obvious similarities, LIS number signs and finger-numeral configurations appear to differ in their efficacy for accessing numerical meaning, at least in hearing subjects. Further investigations will clarify the extent to which these differences are related to visual characteristics of these stimuli or to their variable linguistic value. Finally the LIS sub-base-5 number system impacts on the parity retrieval of signed numbers, suggesting the existence of two alternative routes (lexical and semantic) for extracting parity information from signed numbers irrespective of linguistic expertise. Taken together, these findings crucially contribute to clarifying which features of signs (e.g. number magnitude, sign perspective) and Arabic numbers can influence number processing and parity retrieval in a direct comparison of deaf and hearing individuals.

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