The development of the SNARC-effect: Evidence for early verbal coding

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Abstract

In a recent study, Gevers and colleagues (2010) showed that the SNARC (Spatial Numerical Association of Response Codes) effect in adults does not only result from spatial coding of magnitude (e.g., the mental number line hypothesis), but also from verbal coding. Because children are surrounded by rulers, number lines, etc. in the classroom, it is intuitively appealing to assume that they first use their mental number line to represent numbers and that only later in development a verbal recoding of magnitude information takes place. However, this hypothesis has never been tested. The goal of the present study was to define the developmental pattern of both accounts (spatial and verbal) in explaining the SNARC effect. To this end, 9- and 11-year old children were tested in a magnitude comparison task. Surprisingly, clear and robust evidence for verbal coding of magnitude information was observed in both age groups. Our results imply that the ability to use verbal coding of magnitude information is robustly present early in formal schooling.

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Interactions between number and space have received a lot of interest in the research literature (see Hubbard et al., 2005, for a review). The idea that numbers are internally represented on a continuous left-to-right oriented line (the “mental number line”) has been omnipresent in the numerical cognition literature (e.g., Bachtold, Baumuller, & Brugger, 1998; Dehaene, Bossini, & Giraux, 1993; Fias, Lauwereyns, & Lammertyn, 2001; Gevers, Reynvoet, & Fias, 2003). The SNARC effect (Spatial Numerical Association of Response Codes) has been regarded as an important marker for such a spatial representation of numbers. The SNARC effect reflects the observation that responses are faster for relatively small numbers with the left-hand side and faster for relatively large numbers with the right-hand side (Dehaene et al., 1993). According to the spatial account, the SNARC effect results from a tight correspondence between the position of a number on a continuous left-to-right oriented representational medium (the “mental number line”) and the spatial position of the response (Restle, 1970). Recently however, this strict spatial account of the SNARC effect has been questioned (Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Fias, Van Dijck, & Gevers, 2011; Proctor & Cho, 2006) and a verbal account was proposed. According to this account, the SNARC effect results from an association between verbal codes such as “small” and “left,” on the one hand, and between “large” and “right,” on the other. Gevers and colleagues (2010, see also Santens & Gevers, 2008) showed that the SNARC effect in adults can result from both spatial and verbal processing. However, when both accounts were directly pitted against one another, verbal processing was the dominant processing mechanism.

Despite a considerable number of SNARC studies in the adult literature, only a few developmental studies exist. The first study to investigate a SNARC effect in children was performed by Berch, Foley, Hill, and Ryan (1999). Using a parity judgment task (Is a presented number odd or even?), a SNARC effect was observed from 9 years on and it decreased with increasing age[1]. However, the parity judgment task might not be an ideal task to look for a SNARC effect because magnitude information is irrelevant to make parity judgments. This makes the SNARC effect dependent on automatic activation of magnitude information rather than on the characteristics of its representation (e.g., Fias & Fischer, 2005; Van Galen & Reitsma, 2008).

A second study compared the SNARC effect in 9-year-old visuospatially disabled children with matched controls (Bachot, Gevers, Fias, & Roeyers, 2005). Using a magnitude comparison task (“Is a presented number smaller or larger than 5?”), Bachot and colleagues showed that the SNARC effect was absent in the visuospatially disabled children but present in the matched controls.

A last study on the development of the SNARC effect was conducted by Van Galen and Reitsma (2008). They tested 7, 8, and 9 year old children who performed both a magnitude comparison task (where magnitude information is relevant) and a detection task (where magnitude information is irrelevant). The authors observed a SNARC effect in the magnitude comparison task from 7 years on, but only from 9 years on in the detection task. It was concluded that 7-year-old children represent number magnitude in the same way as adults do, that is, they associate small numbers with “left” and large numbers with “right,” but that automatic access to magnitude information only appears at the age of 9.

The goal of the present study is to further define the developmental trajectory of the SNARC effect in children by focusing on the development and the interplay between spatial and verbal processing of numbers. Verbal processing was observed as the dominant mechanism in adults (Gevers et al., 2010). In line with the conclusions of Van Galen and Reitsma (2008), it could be expected that verbal processing is also the dominant mechanism in children, at least when magnitude information is relevant to the task. On the other hand, Berch et al. (1999) observed a decreasing SNARC effect with increasing age while at the same time they observed that the influence of linguistic factors increased with age. This “linguistic markedness of response codes” or “MARC” effect entails that odd numbers are associated with faster left-hand side responses while even numbers are associated with faster right-hand side responses (Nuerk, Iversen, & Willmes, 2004). Based on these results, one could predict a development from dominant spatial processing at earlier ages towards dominant verbal processing at later ages. Furthermore, because elementary school children are surrounded by rulers, number lines, etc. in the classroom and because they are in the middle of learning the association between numbers and space (e.g., the numbers’ positions on a ruler), it could be expected that spatial coding is the dominant processing mechanism in children. A dominance of spatial coding over verbal coding is also expected based on Bachot et al.’s (2005) study, where no SNARC effect was observed in visuospatially disabled children.

We used a magnitude comparison task to investigate whether spatial or verbal mechanisms are driving the SNARC effect in 9 and 11 year old children. We started at 9 years old because younger children do not yet possess a fully mature knowledge of the words and concepts “left” and “right” (Rigal, 1994), which is a prerequisite for the task we used. We used the same task design as Gevers et al (2010, experiment 4), of which a graphical illustration is provided in Figure 1. In the original experiment, 24 adult participants were presented with numbers that appeared centrally on a computer screen and were flanked by two verbal response labels. They had to decide whether the number was smaller or larger than 5 by pressing on the side of the corresponding response label. For instance, they had to press the word “LEFT” (in Dutch: LINKS) if the target number was smaller than 5 and the word “RIGHT” (in Dutch: RECHTS) if the number was larger than 5. The positions of the response labels were uninformative as they varied randomly from trial to trial.

If the response labels are presented in their canonical position (upper half of Figure 1), both the spatial and the verbal account lead to the same prediction. For instance, both spatial and verbal coding predict faster responses with the left hand side when presented with “LEFT 1 RIGHT” but faster responses with the right hand side when presented with “LEFT 9 RIGHT”. However, when the labels are presented atypically (lower half of Figure 1), then the two accounts lead to a different prediction. For instance, if presented with “RIGHT 1 LEFT,” the spatial account predicts faster left-hand responses (because the number 1 is positioned left on the number line, that is associated with responses in the left side of space), whereas the verbal account predicts faster right-hand responses (because small is associated with the verbal label “LEFT” that is presented on the right side). When presented with “RIGHT 9 LEFT,” the spatial account predicts faster right-hand responses (because the number 9 is positioned right on the number line, that is associated with responses in the right side of space), whereas the verbal account predicts faster left-hand responses (because large is associated with the verbal label “RIGHT” that is presented on the left side). The data obtained by Gevers and colleagues (2010) showed clear evidence for the verbal account. That is, adults associated small numbers with the word “left” and large numbers with the word “right”.

Method

Participants. Forty-six children of the same elementary school in the Flemish part of Belgium participated in this study. There were 23 3rd graders (15 girls and 8 boys; mean age 8 years 9 months; range 8 years 5 months – 9 years 11 months) and 23 5th graders (10 girls and 13 boys; mean age 10 years 10 months; range 10 years 6 months – 11 years 11 months). The children participated only when they, as well as their teachers and parents, consented. Children with known developmental or language delays or diagnosed learning or behavioral disorders (e.g., ADHD) were excluded from participation. The children's data were compared with the data obtained in 24 undergraduates (age range: 18-23) of Ghent University, tested by Gevers et al. (2010; Experiment 4).

Stimuli and Procedure. We adapted the procedure of Experiment 4 in Gevers et al. (2010) in such a way that it was suitable for elementary school children. All responses were registered with a touch screen. The children were tested in two sessions that lasted about 25 minutes each. The second session took place approximately one week after the first one. Order of sessions was counterbalanced across participants.

At the start of each session, children were told that they would play a "number game," in which they had to gain points. They were told that they would see numbers and had to decide whether the number was smaller or larger than five. At the end of the session, they could "exchange" their points for a small reward.

The first session started with 4 practice trials to familiarize with the task. Instead of numbers, pictures of animals were presented and the child had to compare the size of the presented animal with the size of a dog. Two trials with a word congruent mapping (the response label "LINKS" [left] on the left side of the screen, and the response label "RECHTS" [right] on the right side) and two trials with a word incongruent mapping (the response label "LINKS" [left] on the right side of the screen, and the response label "RECHTS" [right] on the left side) were performed. Other procedural details were identical to the experimental trials.

In both sessions, the children performed a practice block (8 trials) and an experimental block (160 trials). Each trial started with a fixation mark (a traffic sign with an exclamation mark) that was presented for 750ms. Subsequently, the words "LINKS" and "RECHTS" appeared on the left and the right side of the screen. In half of the trials, the response label

“LINKS” appeared on the left side of the screen and the response label “RECHTS” appeared on the right side of the screen (Congruent word position; see upper half of Figure 1). In the other half of the trials, this position was reversed (Incongruent word position; see lower half of Figure 1). The position of the response labels varied randomly from trial to trial. After 1500ms, a red button appeared in between the words. As soon as the child released this button, the number 1, 2, 8, or 9 was presented (in black, font Arial). In one session, children had to respond to the magnitude of the numbers by pressing on the word “LINKS” if the target number was smaller than 5 and pressing on the word “RECHTS” if the target number was larger than 5. In the other session this response mapping was reversed: Now children had to press on the word “RECHTS” if the number was smaller than 5 and on the word “LINKS” if the number was larger than 5. After the response, the screen remained blank for 1000ms before a new trial started.

Trial-by-trial feedback (a sad or happy face, presented for 1500 ms) was only provided in the practice blocks. In the experimental block, there was a break (during which pictures of coins, medals and a cup were presented) after every series of 32 trials.

Results

Errors were made on 2.0% of the trials (children) and 6.2% of the trials (adults) and were not further analyzed. Median correct RTs were subjected to a 3 (Age) x 2 (Word Congruency) x 2 (Physical Congruency) ANOVA (see Table 1). Age (3rd vs. 5th grade vs. adults) was a between-subjects factor and Word Congruency and Physical Congruency were within-subject factors. A word congruent trial means that the word “LEFT” was presented left on screen and the word “RIGHT” was presented right on screen, whereas a word incongruent trial means that the word “LEFT” was presented right on screen and the word

"RIGHT" was presented left on screen. Physically congruent trials were trials where the children had to respond to small numbers with their left-hand side and to large numbers with their right-hand side; physically incongruent trials were trials where the children had to respond to small numbers with their right-hand side and to large numbers with their left-hand side. Note that the spatial account predicts a main effect of physical congruency (i.e., a SNARC effect, or effect of touching the physically congruent side of the screen), but no interaction with word congruency, whereas the verbal account predicts an interaction between physical congruency and word congruency. For both accounts, interactions with age may indicate developmentally different processes.

The main effect of Age was significant, $F(2,67) = 60.14$, $MSe = 361151$, $\eta_p^2 = 0.47$, $p<.001$: adults (630ms) responded faster than 5th graders (1001ms), $F(1,67) = 31.87$, $\eta_p^2 = 0.32$, $p<.001$, who responded faster than 3rd graders (1585ms), $F(1,67) = 37.85$, $\eta_p^2 = 0.36$, $p<.001$. The main effects of Word Congruency and Physical Congruency were not significant (both Fs<1), but their interaction was, $F(1,67) = 24.70$, $MSe = 148717$, $\eta_p^2 = 0.27$, $p<.001$.

Subsequent analyses showed that this Word Congruency x Physical Congruency interaction was significant at all ages (each $p < .05$; see Figure 2). In the Word congruent condition, Physically Congruent trials were responded to 221ms faster than Physically Incongruent trials, $F(1,67) = 31.22$, $\eta_p^2 = 0.32$, $p<.001$. However, in the Word Incongruent condition, the effect was reversed: Physically Congruent trials were responded to 237ms slower than Physically Incongruent trials, $F(1,67) = 34.83$, $\eta_p^2 = 0.34$, $p<.001$. The 3-way interaction between Age, Word Congruency, and Physical Congruency was also significant, $F(2,67) = 4.07$, $MSe = 148717$, $\eta_p^2 = .06$, $p<.05$ (see Figure 2). Although the Word Congruency x Physical Congruency interaction was significant in all three age groups, planned comparisons showed that this interaction was significantly larger in 5th graders than in adults, $F(1,67) = 4.92$, $\eta_p^2 = .07$, $p<.05$, and tended to be larger in 3rd graders than in adults,

$F(1,67) = 3.47$, $\eta_p^2 = .05$, $p<.07$, respectively[2]. In sum, the results support the verbal account, and indicate that both children and adults rely on verbal coding rather than on spatial coding.

Similar to Gevers et al. (2010), the SNARC effect was also tested by means of regression analyses. In this method, the difference between correct RTs on the right-hand side and correct RTs on the left-hand side is entered in a regression analysis for each participant separately with magnitude as predictor (e.g., Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Lorch & Myers, 1990). The regression weight of the magnitude predictor is then used as an index of the SNARC effect. Very specific predictions can be made. If the spatial account is correct, a congruency is expected between the magnitude of the number and the response side. Therefore, responses to the left hand side are expected to be faster for small numbers and faster to the right hand side for large numbers – irrespective of the words presented in the response labels. Hence, this account predicts a negative SNARC slope for both the congruent and incongruent word position conditions. According to the verbal account, on the other hand, a congruency is expected between the number and the response label. Therefore, if word position is congruent we expect again a negative regression slope. However, if word position is incongruent, we expect faster responses to the left hand side for large numbers (to the word "RIGHT") and faster responses to the right hand side for small numbers (to the word "LEFT"). Hence, this account predicts a negative regression slope when word position is congruent but a positive regression slope when word position is incongruent. The regression plots are shown in Figures 3A and 3B (for 3rd and 5th graders, respectively) and in Figure 3C (for adults, taken from Gevers et al., 2010; Experiment 4).

Clear evidence for the verbal account was obtained. For all age groups, a significant SNARC effect in the Word Congruent condition was observed, $t(22) = -2.61$, $p=.02$, for 3rd graders, $t(22) = -3.63$, $p<.01$, for 5th graders, and $t(23) = -2.03$, $p<.06$, for adults. Also for all age groups, a reversed SNARC effect was observed in the Word Incongruent condition, $t(22)$

= 1.93, p=.06, for 3rd graders, $t(22) = 3.89$, p<.01, for 5th graders, and $t(23) = 3.02$, p<.001, for adults. Importantly, a dependent samples t-test showed that the SNARC slopes differed significantly between the Word Congruent and the Word Incongruent condition, $t(22) = 2.28$, p=.03, for 3rd graders, $t(22) = 3.78$, p<.01, for 5th graders, and $t(23) = 2.93$, p<.01, for adults. Further, 3rd graders showed steeper slopes than did adults, $t(45) = 1.65$, p=.10, for the Word Incongruent condition and $t(45) = 2.34$, p<.05, for the Word Congruent condition. The same was true for 5th graders, $t(45) = 2.84$, p<.01, for the Word Incongruent condition and $t(45) = 2.74$, p<.01, for the Word Congruent condition. There was no difference between 3rd and 5th graders, both ts<1. Taken together, these results clearly show that verbal coding dominates the SNARC effect from 9 years on.

General Discussion

Nine- and 11-year-old elementary school children performed a magnitude comparison task that was designed to test the relative contributions of spatial and verbal coding in the SNARC effect. A previous study showed that verbal coding dominates the SNARC effect in adults (Gevers et al. 2010). The present study shows that the SNARC effect in 9 and 11 year old children is also more dominantly driven by verbal coding. More specifically, the data indicate that by 9 years of age children associate small numbers with the word “left” (and less strong with the left side of space) and large numbers with the word “right” (and less strong with the right side of space).

Because participants were asked to respond to the verbal information and not to the spatial information, one might argue that our paradigm *biased* participants toward verbal coding. This was not the case, however, as we will argue in two points. First, to prevent a bias toward verbal coding, we deliberately chose a magnitude comparison task and not a parity judgment task, because labeling a number as odd or even is typically a verbal task. Second, robust results in line with verbal coding were obtained both when the response labels were presented in their canonical (word congruent) position (LEFT 1 RIGHT) as well as when they were presented in their atypical (word incongruent) position (RIGHT 1 LEFT). If participants would be biased to focus on verbal coding, a strong effect of word congruency would emerge. Indeed, if the task would favor verbal processing, children would need time to inhibit the (task-irrelevant) spatial coordinates and would hence be slower on word incongruent trials than on word congruent trials. However, such a main effect of word congruency was not observed. Hence, it can be concluded that the present paradigm provides a powerful tool to measure both spatial and verbal coding of numbers in children. Nevertheless, it remains interesting to extend the present paradigm with a condition with non-lateralized response labels (e.g. GREEN 1 BLUE) to investigate whether spatial coding is present in children in complete absence of verbal-spatial coding.

Second, several theoretical implications emerge from our findings. In their computational model of the SNARC effect, Gevers et al. (2006) assume that the SNARC effect results from *learned* connections between magnitude labels (small/large), on the one hand, and spatial representational labels (left/right) on the other hand. Apparently, these connections are learned relatively early in development, and are resistant to extensive exposure to external spatial representations of number such as number lines, rulers, calendars, etc. Associations between numbers and physical space seem only to be dominant when participants are explicitly instructed to use a spatial representation, such as a clock face (e.g., Bachtold et al., 1998) or a number line (e.g., Siegler & Opfer, 2003). The tendency to associate numbers with verbal concepts rather than with space probably stems from the importance of language in our world. From birth on, we are immersed in a linguistic context that determines our cultural conventions and verbal concepts. When we grow older, there is a co-development of number concepts and number words (Wiese, 2007). Hence, and in contrast to Berch et al. (1999), linguistic influences do not override spatial associations with age. At least from the age of 9 years on, it seems that verbal associations are dominant.

Our results fit with those obtained by Van Galen and Reitsma (2008), who observed that the SNARC effect gradually changed from continuous to categorical with increasing age. According to these authors, adults and older children (from 9 years old) use rough categorizations as “small” and “large,” which are – as shown in the present study – very suitable for verbal coding. Younger children, in contrast, would rather compare numbers using an algorithmic procedure, which may be less suitable for verbal coding. The ability of phonological coding indeed arises during development and more specifically around 8 years (Pickering, 2001). Studies using spatial tasks such as picture recall (e.g., Palmer, 2000) or wayfinding (e.g., Fenner, Heathcote & Jerrams-Smith, 2000) found that young children (5-6 years) exclusively rely on spatial coding, while after the age of 8 years they use a more phonological approach. This is in line with what we found: already from 9 years on numbers are coded in a verbal way. It would be interesting to study the interaction between verbal and spatial coding of numbers in even younger children (before the age of 8), provided that a new research paradigm is designed to make the task suitable for young children.

Our findings fit nicely with a recent claim that the number line is not innate in the human brain (Nunez, 2011). Nunez argues that the number line is a human concept that is culturally and historically mediated by language, external representations, and technology (e.g., writing and notation). There are at least two reasons for the ubiquitous presence of number-space associations in our modern world (Nunez, Doan, & Nikoulina, 2011). First, most studies tested a biased sample, namely Western, educated adults, in which the spatial representation of number has been culturally privileged and enhanced. In the present study, we showed that conceptual mappings (e.g., between small and “left”) exert their effects from early age on, and override spatial mappings (e.g., between small and the left side of space) already in 9-year olds. Hence, the challenge for future research is testing the relative strength of both *visuo*-spatial coding and *verbal*-spatial coding in younger (less educated) participants and in other cultures. Second, most studies used only spatial response modes such as mapping numbers on a line (e.g., Siegler & Opfer, 2003). Recent results obtained in experiments with non-spatial response modes indicate that adults' number representation (the "core number sense") is not exclusively spatial (Nunez et al., 2011). Similarly, our results imply that the ability to use verbal coding of magnitude information is robustly present early in formal schooling and overrides spatial coding.

Conclusion

By the end of the 3rd grade, children have formed an association between small numbers and the concept "left" and between large numbers and the concept "right". These verbal associations are stronger than spatial associations such as between small numbers and the left side of space or between large numbers and the right side of space. Thus, whereas number-space associations do not occur automatically in adults (Gevers et al., 2010; Nunez et al., 2011) or children (this study), conceptual mappings do appear early in development. Although it remains theoretically possible that spatial coding is also present at this early stage in development, it does not override verbal coding.

Foot Notes

1. In contrast, a recent meta-analysis of the SNARC effect revealed that the size of the SNARC effect *increased* with age (Wood, Willmes, Nuerk, & Fischer, 2008). However, besides the three developmental studies also described here (Bachot et al., 2005; Berch et al., 1999; Van Galen & Reitsma, 2008), this meta-analysis mainly incorporated studies with young and older adults (up to 55 years).
2. In order to test for scaling effects, we performed a similar 3 x 2 x 2 ANOVA on log-transformed median RTs. If the interactions with Age remain significant after log transformation, we can safely conclude that they are genuine (see De Brauwer & Fias, 2009, for an elaboration on this topic). Results were identical to those on non-transformed RTs; that is, we observed a significant main effect of Age, a significant Word Congruency x Physical Congruency interaction, and a significant Age x Congruency x Physical Congruency interaction (each $p<.05$).

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Table 1

Median correct response times (in milliseconds) as a function of Age, Word congruency, and Physical congruence. Standard errors between brackets.

	Word congruent		Word incongruent	
	Physical congruent	Physical incongruent	Physical congruent	Physical incongruent
3rd graders	1407 (66)	1782 (84)	1758 (86)	1394 (64)
5th graders	872 (66)	1109 (84)	1155 (86)	868 (64)
adults	600 (64)	650 (83)	664 (84)	605 (63)

Figure 1

Illustration of predictions for both the spatial account and the verbal account when word positions are congruent (upper half) or incongruent (lower half). Hand positions indicate the side of response that is preferred according to the two respective accounts. Physical congruency is not depicted in this figure because predictions are similar for physical congruent and physical incongruent trails.

Note. Figure adapted from Gevers et al. (2010).

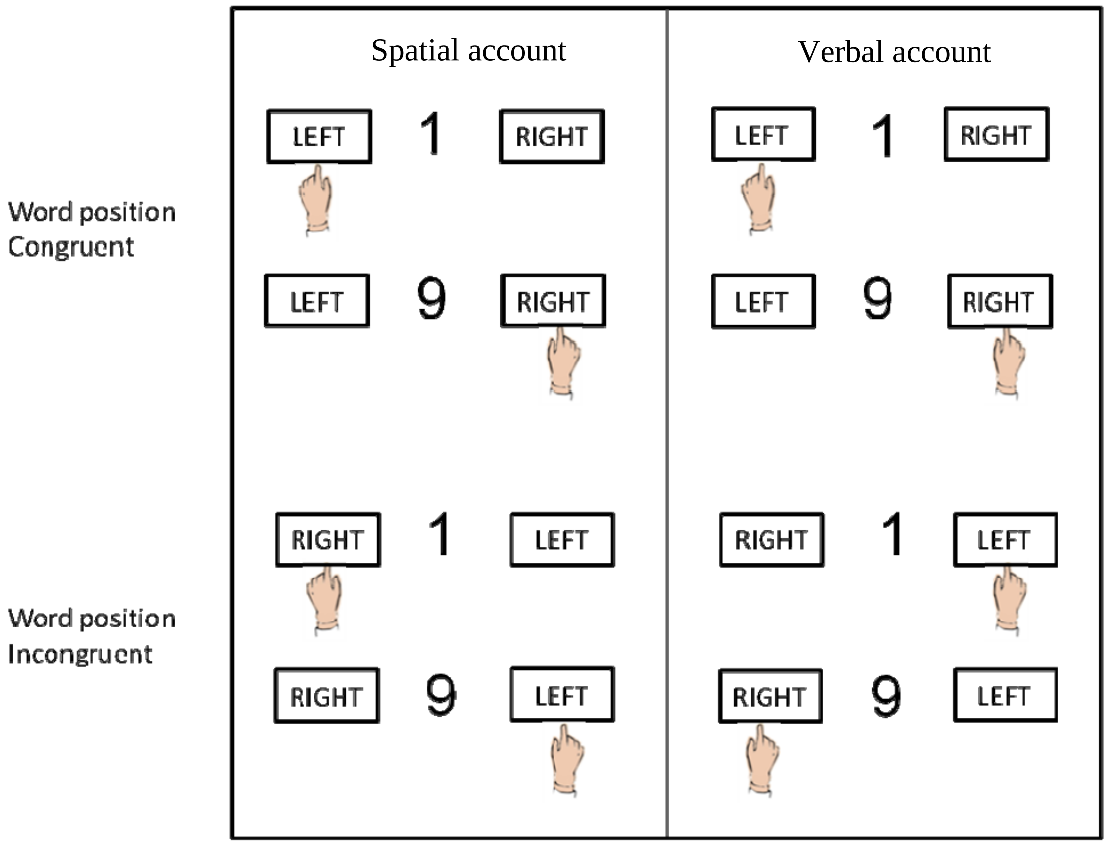
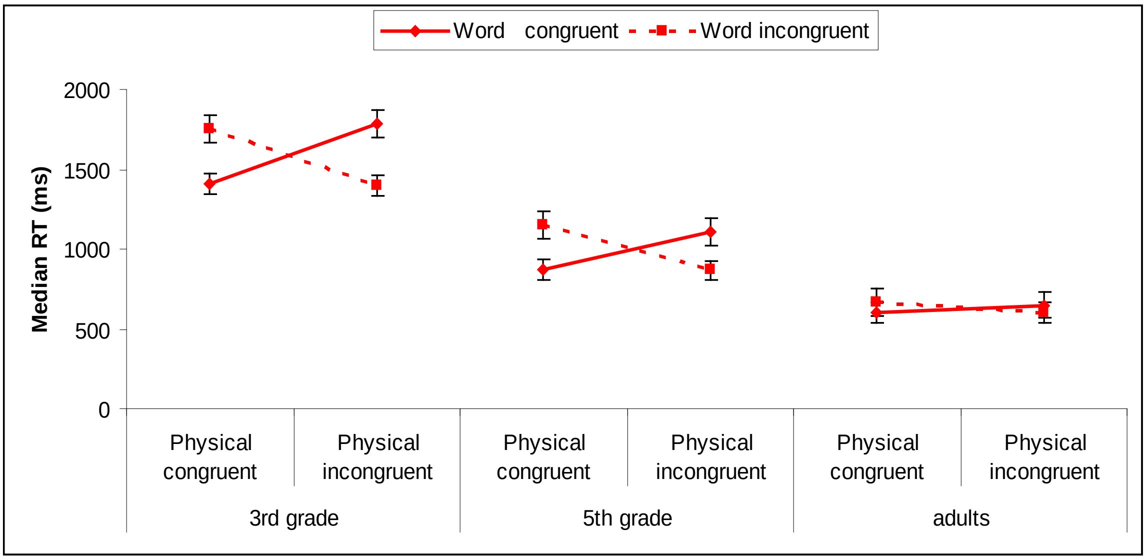


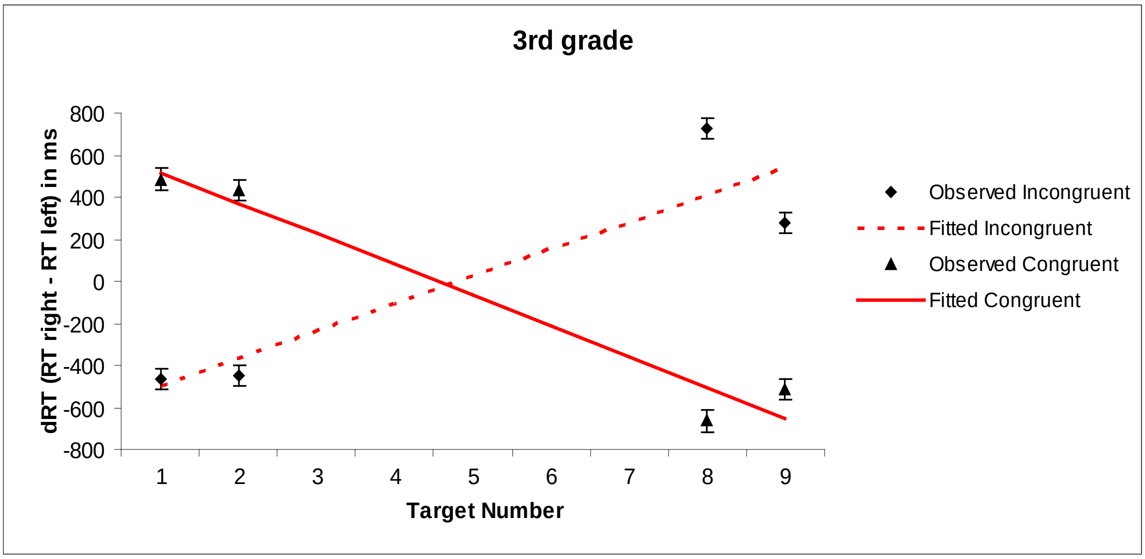
Figure 2

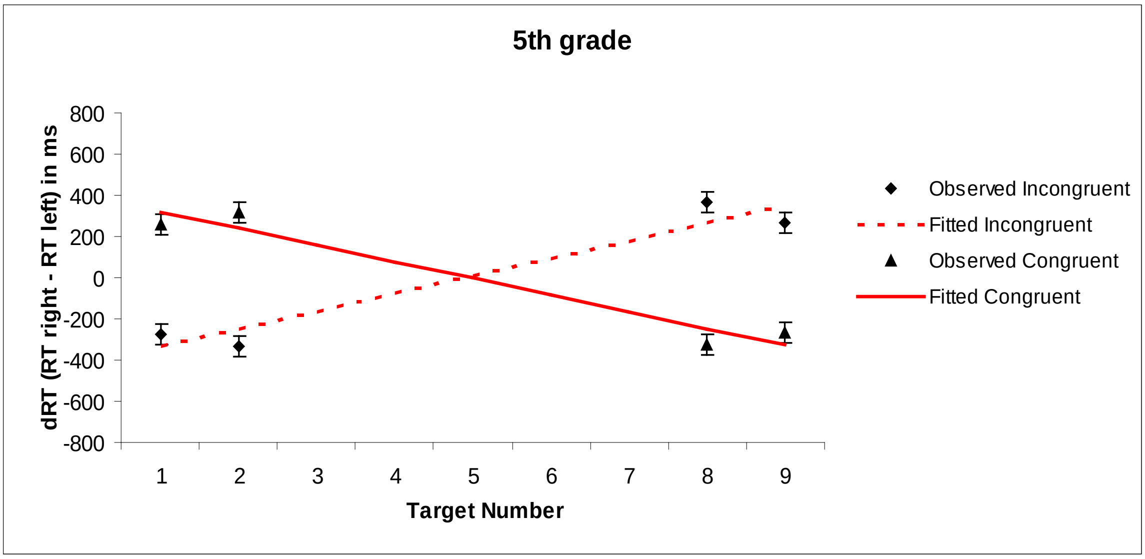
Median response times (ms) as a function of Word Congruency, Physical Congruency, and Age.

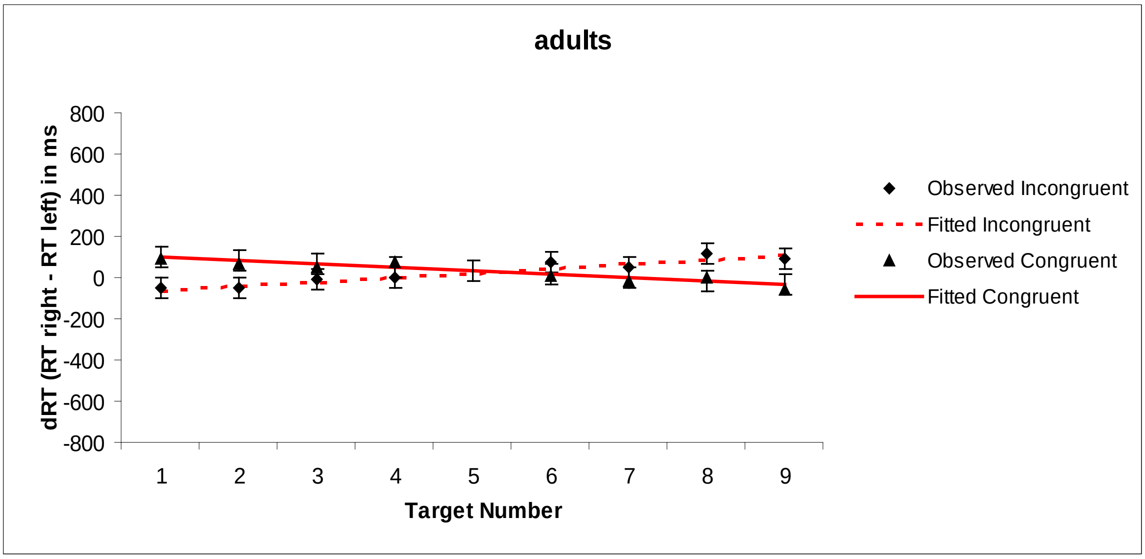


Figures 3A, 3B, and 3C

The regression line represents RT differences between right-handed minus left-handed responses as a function of magnitude in the Word Congruent condition (solid line) and in the Word Incongruent condition (dashed line) for 3rd graders (Figure 3A), 5th graders (Figure 3B), and adults (Figure 3C). Please note that the data in Figure 3C are identical to the data in Figure 3B in Gevers et al., (2010), where the Y axis' endpoints are -160 to 140. For reasons of clarity, the Y axis' endpoints are similar in all the present figures (-800 to 800).


3rd grade
800
600
400
200
0
-200
-400
-600
-800
dRT (RT right - RT left) in ms
1
2
3
4
5
6
7
8
9
Target Number
Observed Incongruent
Fitted Incongruent
Observed Congruent
Fitted Congruent


5th grade
800
600
400
200
0
-200
-400
-600
-800
dRT (RT right - RT left) in ms
1
2
3
4
5
6
7
8
9
Target Number
Observed Incongruent
Fitted Incongruent
Observed Congruent
Fitted Congruent


adults
800
600
400
200
0
-200
-400
-600
-800
dRT (RT right - RT left) in ms
1
2
3
4
5
6
7
8
9
Target Number
Observed Incongruent
Fitted Incongruent
Observed Congruent
Fitted Congruent