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Short article

Spatial associations in relational reasoning: Evidence for a SNARC-like effect

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Relational reasoning (A > B, B > C, therefore A > C) shares a number of similarities with numerical cognition, including a common behavioural signature, the *symbolic distance effect*. Just as reaction times for evaluating relational conclusions decrease as the distance between two ordered objects increases, people need less time to compare two numbers when they are distant (e.g., 2 and 8) than when they are close (e.g., 3 and 4). Given that some remain doubtful about such analogical representations in relational reasoning, we determine whether numerical cognition and relational reasoning have other overlapping behavioural effects. Here, using relational reasoning problems that require the alignment of six items, we provide evidence showing that the subjects' linear mental representation affects motor performance when evaluating conclusions. Items accessible from the left part of a linear representation are evaluated faster when the response is made by the left, rather than the right, hand and the reverse is observed for items accessible from the right part of the linear representation. This effect, observed with the prepositions *to the left of* and *to the right of* as well as with *above* and *below*, is analogous to the SNARC (Spatial Numerical Association of Response Codes) effect, which is characterized by an interaction between magnitude of numbers and side of response.

Keywords: Relational reasoning; Transitive reasoning; Numerical cognition; SNARC.

It has often been claimed that linear reasoning problems involving transitive relations (e.g., *taller than, to the left of*) are solved by the construction of a unified, analogical, and spatial representation of the premises (De Soto, London, & Handel, 1965; Huttenlocher, 1968; Johnson-Laird, 1983). For example, to infer the conclusion A > C from the premises A > B and B > C, participants are assumed to construct a single linear array integrating the premises: A–B–C. Much of the empirical support for this claim comes from the *symbolic distance effect* (SDE), showing that reaction time in evaluating pairs decreases as the number of intervening items in a pair increases (Evans, Newstead, & Byrne, 1993; Potts, 1974). Given the premises A > B, B > C, C > D, D > E, E > F, a test item containing a relatively distant pair like B > D is evaluated more

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rapidly than an item containing an adjacent pair like B > C, even though the latter was explicitly provided. This effect can be explained by the nature of the representation: If people construct a mental linear array to represent the premises (A–B–C–D–E–F), items of a distant pair are more easily distinguishable than items of an adjacent pair.

The SDE observed in relational reasoning echoes with the SDE reported in numerical cognition. The latter literature shows that when comparing two numbers (say, to determine which is larger), participants are faster at making their decisions when the compared numbers are distant (e.g., 35 and 72) than when they are close (e.g., 48 and 51; Moyer & Landauer, 1967). The similarity of the two effects across two literatures naturally suggests that they are manifestations of a single phenomenon.

However, some contest the generality of the SDE in relational reasoning. Indeed, when relational orders involve categories (see Sailor & Shobern, 1993) or a complex network of relations (Warner & Griggs, 1980) the SDE disappears. Likewise, when participants are not overtrained, the SDE recedes (Favrel & Barrouillet, 2000; Wright, 2006). This suggests that the analogical representation is not as ordinary as one might think and that it specifically emerges in order to address particular characteristics of the task.

More convincing evidence in favour of the idea that the representation has an unambiguous spatial component would be provided by an effect showing that such a mapping affects an action performed in a physical space. Interestingly, such an effect exists in numerical cognition. The SNARC (Spatial Numerical Association of Response Codes) effect provides the best evidence that numbers are spatially organized on a mental line and is characterized by an interaction between magnitude of numbers and side of response (Dehaene, Bossini, & Giraux, 1993; Gevers & Lammertyn, 2005). When asked to compare the magnitude of numbers (or to classify them as even or odd), participants answer faster for small numbers with the left hand than with the right hand. The reverse pattern is observed for large numbers (Dehaene et al., 1993; Dehaene, Dupoux, & Mehler, 1990).

Here, we investigate whether a SNARC-like effect arises in relational reasoning. Evidence of such an effect would provide more direct support for the existence of analogical processes in relational reasoning than the SDE alone. We hypothesize that if participants construct an array for relational reasoning problems that is similar to the mental number line, one should observe a SNARC-like interaction (where the position of an item on the line ought to affect the hand that provides the response).

How can this be operationalized in a reasoning study? As a first step it would be reasonable to expect—for a linear ordering of the sort A > B > C > D > E > F—that the pairs AB, BC, and AC (if represented horizontally) should be evaluated correctly faster with the left hand than with the right. Conversely, the pairs DE, EF, and DF should be evaluated correctly faster with the right hand than with the left. In what follows, the pairs AB, BC, and AC will be conventionally termed *left pairs* and the pairs DE, EF, and DF *right pairs*.

EXPERIMENT 1

Experiment 1 consisted of four 6-term linear ordering problems (A > B > C > D > E > F) involving the prepositions *to the left/right of* (thus referring to an explicit left–right orientation). The experiment followed a 5 (number of intervening items: from 0 to 4) × 2 (truth value: true, false) × 2 (response side: left hand, right hand) × 2 (preposition: *to the left of, to the right of*) within-subject design.

Method

Participants

A total of 26 right-handed French undergraduates participated (8 males).

Materials

Participants were presented four sets of spatial descriptions (written in French). Each set involves a linear ordering of six individuals (i.e., A–B–C–D–E–F), each of whom was identified by a common, one-syllable surname (whose first letter was unique). A spatial description provided five adjacent pairs of the linear ordering (i.e., AB, BC, CD, DE, EF), but not necessarily in a sensible order. Here is an example:

Six friends are at the movie theatre. They are seated in the same row of seats. Anne is to the left of Louise, Claire is to the left of Eve, Maud is to the left of Anne, Jeanne is to the left of Claire, Louise is to the left of Jeanne.

For each of the four sets of spatial descriptions, 30 test propositions (15 valid, 15 invalid) were prepared in order to cover all possible pairwise spatial relations between the characters in the array. This allows one to manipulate the number of intervening items in each pair (0, 1, 2, 3, or 4). Two descriptions used the preposition *to the left of* (*à gauche de*) and the other two used the preposition *to the right of* (*à droite de*). The preposition used in the test items always matched those used in the spatial descriptions.

Procedure

Participants were presented a spatial description (on a sheet of paper) and were instructed to learn its content. They were free to take as much time as necessary, and they were allowed to take notes. When participants considered themselves ready, the description and the notes were removed. They then had to evaluate a set of propositions assessing their knowledge about the content of the description. The propositions were presented using the software *Presentation* (Neurobehavioral Systems, Version 9.20, www.neurobs.com). Each trial consisted of a fixation dot lasting 1,000 ms followed by a test proposition that remained until the participant responded by pressing one of two corresponding response keys (true/false) with the index finger of their left or right hand. Participants were instructed to respond as fast as possible, but without neglecting accuracy.

The experiment was divided in two experimental sessions in order to counterbalance the assignment of response keys (left hand: "Q" and right hand: "M", AZERTY keyboard) within each subject (Dehaene et al., 1993). Within each experimental session, participants received two types of prepositions (*to the left/right of*). Session order and problem order within each session was counterbalanced, and trial order within each problem was randomized.

Results and discussion

A total of 4 participants were excluded from analyses because their error rate exceeded 30% and 1 because her mean reaction time (RT) for correct responses exceeded 10,000 ms. The average error rate over remaining participants was 10%. All error trials were removed when analysing the RT data. For each participant, RTs less than 600 ms and RTs more than 3 standard deviations from the mean were excluded from the analyses. This resulted in less than 1% of the trials being removed from the data set.

To investigate the presence of a SNARC-like effect in relational reasoning, we focus here exclusively on the six test prepositions (three true, three false) involving the *left pairs* (AB, BC, AC) versus the six test propositions involving the *right pairs* (DE, EF, DF). Because correct RT values were found to be normally distributed (Shapiro–Wilks W test, $p > .2$), we carried out a 2×2 within-subject analysis of variance (ANOVA) with the factors position of the pair (left pair, right pair) and response side (left hand, right hand) on correct RTs (Figure 1A). Contrary to our hypothesis, the interaction Position of the Pair $\times$ Response Side failed to reach significance, $F(1, 20) = 1.85$, $MSE = 621{,}896$, $p = .19$, indicating that left pairs were not evaluated significantly faster with the left hand than with the right hand (left hand 4,989 ms, right hand 5,342 ms) and right pairs faster with the right hand than with the left hand (left hand 5,302 ms, right hand 5,188 ms).

One explanation for the lack of a SNARC-like effect here could lie in the fact that left and right pairs (AB, BC, AC versus DE, EF, DF), as defined in our analysis, are not lateralized enough to elicit an association with a side of space. The present task, in contrast with number comparisons tasks, involves a relatively high

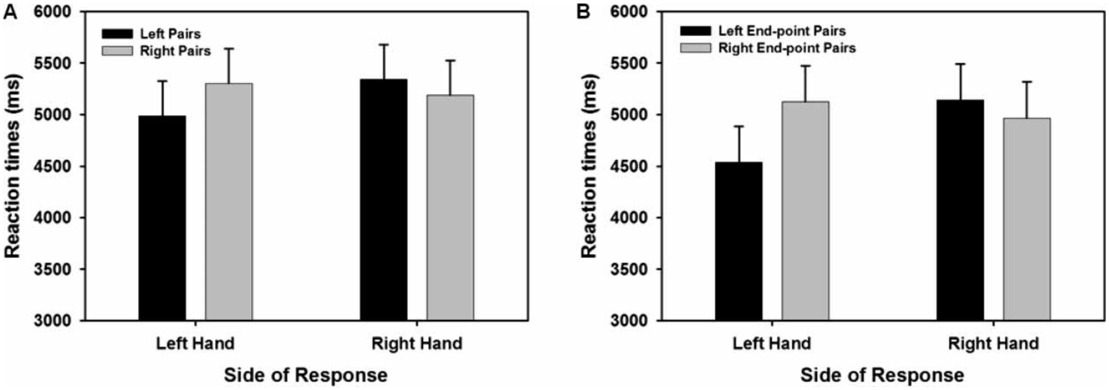

Figure 1. *Experiment 1. (A) Mean correct RTs as a function of side of response (left hand vs. right hand) and position of the pair (left pairs: AB, BC, AC; right pairs: AB, BC, AC). (B) Mean correct RTs as a function of side of response (left hand vs. right hand) and position of the end-point pair (left end-point pairs: AB, AC; right end-point pairs: EF, DF). Error bars show within-participants 95% confidence intervals (Loftus & Masson, 1994).*

proportion of pairs immediately close to the middle of the linear representation (the BC and DE pairs amount to a third of the pairs investigated). It is likely that those pairs are too close to the middle of the linear mental representation constructed by the subjects (A–B–C–D–E–F) to be lateralized. To test this hypothesis, we ran another analysis similar to the one conducted above but we focused only on the test propositions involving left end-point pairs (AB, AC) and right end-point pairs (EF, DF); in other words, the middle pairs BC and DE were removed from the analysis. We thus conducted a 2 × 2 within-subject ANOVA with the factors position of the end-point pair (left end-point pair, right end-point pair) and response side (left hand, right hand) on correct RTs. The interaction Position of the End-Point Pair × Response Side reached significance, $F(1, 20) = 4.54$, $MSE = 675{,}783$, $p < .05$; Figure 1B).

To determine the nature of this interaction, we computed the RT difference (dRT) between right-hand and left-hand responses (i.e., RT righthand − RT left hand) for left and right end-point pairs. As predicted, mean dRT was 765 ms larger for the left than for the right end-point pairs (left end-point pairs, 607 ms; right end-point pairs, −158 ms; $t(20) = 2.13$, $p < .05$, indicating an advantage for left-hand responses to left end-point pairs and for right-hand responses to right end-point pairs. Moreover, such a response hand difference was specific to left and right end-point pairs, as no hand preference was observed on the symmetrical pairs AF, BE, CD (left hand 5,386 ms, right hand 5,351 ms); $t(20) = 0.07$, $p = ns.$

As a whole, this effect appears to be analogous to the SNARC effect observed on numbers (Dehaene et al., 1993). Moreover, the fact that the SNARC-like effect we describe is observed for pairs containing end-terms (i.e., A and F) ascertains that those pairs are spatially represented, a finding that is hard to establish with the SDE since this effect is typically observed for pairs containing only inner items (i.e., B–C–D–E, see Potts, 1974).

Our data also revealed two additional behavioural effects in this paradigm. First, we found a standard SDE on overall mean RTs, as revealed in Figure 2A. Consistent with the SDE, mean RTs decreased as the number of intervening items in the test pair increased. Mean RT was 5,384 ms when the pair did not contain any intervening item (e.g., AB), 5,425 ms when 1 intervening item was present (e.g., AC), 5,300 ms for 2 intervening items (e.g., AD), 4,994 ms for 3 intervening items (e.g., AE), and 4,438 ms for 4 intervening items (e.g., AF). Second, we found that left pairs were evaluated faster than right pairs with the preposition *to the left of* (left pairs 4,828 ms, right

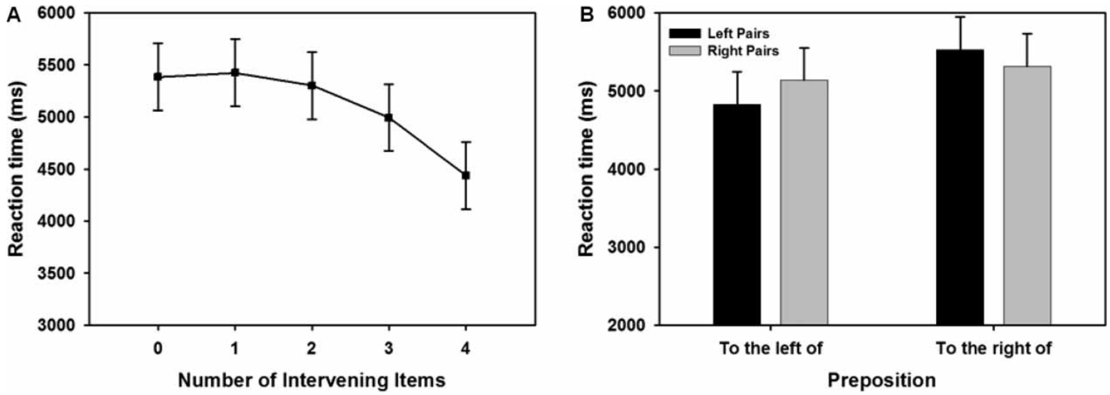

Figure 2. *Experiment 1. (A) Overall mean correct RTs as a function of number of intervening items (0: AB, BC, CD, DE, EF; 1: AC, BD, CE, DF; 2: AD, BE, CF; 3: AE, BF; 4: AF). (B) Mean correct RTs as a function of preposition (to the left of vs. to the right of) and position of the pair (left pairs: AB, BC, AC; right pairs: AB, BC, AC). Error bars show within-participants 95% confidence intervals.*

pairs 5,135 ms), whereas the reverse pattern was obtained with the preposition *to the right of* (left pairs 5,528 ms, right pairs 5,311 ms; see Figure 2B). We refer to this as a "congruence effect" between the position of the items and the lexical marking conveyed by the preposition (Clark, 1969). Under such an interpretation, "X is to the left of Y" would focus attention on the left part of the ordering so that X and Y would be more quickly identified if they are located on that part. In contrast, "Y is to the right of X" would focus attention on the right part of the ordering. However, another interpretation is that descriptions involving *to the left of* will be constructed from left to right, so that leftmost items will be searched first during the construction process (Van der Henst & Schaeken, 2005). This would tend to encourage left-to-right scanning during the evaluation phase so that leftmost items will be reached more quickly. Following the same argument, descriptions involving *to the right of* will favour the processing of rightmost items. Such an explanation is consistent with findings showing that order of mental model construction influences order of output in memory (Baguley & Payne, 1999, 2000; Hörnig, Oberauer, & Weidenfeld, 2005; Taylor & Tversky, 1992).

Experiment 1 is consistent with the hypothesis that participants construct arrays in relational reasoning tasks that affect motor responses in a way that resonates with the mental number line in numerical cognition (Gevers & Lammertyn, 2005). One could, however, argue that this association of items from the left to the right side of space is specifically triggered by the prepositions used, which explicitly refer to a left–right dimension. Experiment 2 was designed to test whether the SNARC-like effect resulting from a left-to-right, linear organization of items could also be observed with other relational expressions. We thus prepared identical relational reasoning problems based on the prepositions *above* and *below* while the response assignment was varied in the same way as in Experiment 1 (left vs. right side of response).

EXPERIMENT 2

Method

Participants

A total of 14 right-handed French undergraduates participated (8 males).

Materials

The materials were the same as those in Experiment 1 except that the prepositions used in Experiment 2 were *above* (*au dessus*) and *below* (*en dessous*).

Procedure

The task and the assignment of response keys were identical to those in Experiment 1.

Results and discussion

A total of 2 participants were excluded from the analyses because their error rate exceeded 30% and 1 because the participant's mean RT for correct responses was above 10,000 ms. The average error rate over participants was 12%. For the remaining participants, all error trials were removed, and all RTs less than 600 ms and more than three standard deviations from the mean were excluded from the analysis (this resulted in 1% of the trials being removed from the data set). Following the same analysis as that in Experiment 1, we focus here on the three upper and lower-pairs (AB, BC, and AC versus DE, EF, and DF) to investigate the presence of a SNARC-like effect.

Normality of the RT values was confirmed by the Shapiro–Wilks *W* test ($p > .5$). We thus performed two different ANOVAs using as a dependent variable either correct RTs from upper and lower pairs (i.e., AB, BC, and AC versus DE, EF, and DF) or correct RTs from upper and lower end-point pairs (i.e., AB and AC versus EF and DF). Unlike Experiment 1, the first repeated measures ANOVA (using RTs from the pairs AB, BC, AC vs. DE, EF, DF) with position of the pair (upper pair, lower pair) and side of response (left hand, right hand) as factors revealed a significant Position of the Pair × Side of Response interaction, $F(1, 10) = 6.40$, $MSE = 329{,}390$, $p < .05$. Mean dRT (RT right hand − RT left hand) was indeed 899 ms larger for the upper than for the lower pairs (upper pairs, 530 ms; lower pairs, −346 ms); $t(10) = 2.53$, $p < .05$, indicating a clear advantage for left-hand responses to upper pairs and for right hand responses to lower pairs (Figure 3A). The second repeated measures ANOVA (using RTs from the end-point pairs AB, AC vs. EF and DF) using the factors position of the end-point pair (upper end-point pair, lower end-point pair) and side of response (left hand, right hand) confirmed the results above (Figure 3B). That is, we observed a marginally significant Position of the End-Point Pair × Side of Response interaction, $F(1, 10) = 3.72$, $MSE = 102{,}101$, $p = .08$ (Figure 3B). Here, mean dRT (RT right hand − RT left hand) was 372 ms larger for the upper than for the lower end-point pairs (upper end-point pairs, 301 ms; lower end-point pairs, −71 ms); $t(10) = 1.93$, $p = .08$. This suggests again a response advantage for left hand to upper end-point pairs and for right hand to lower end-point pairs. As

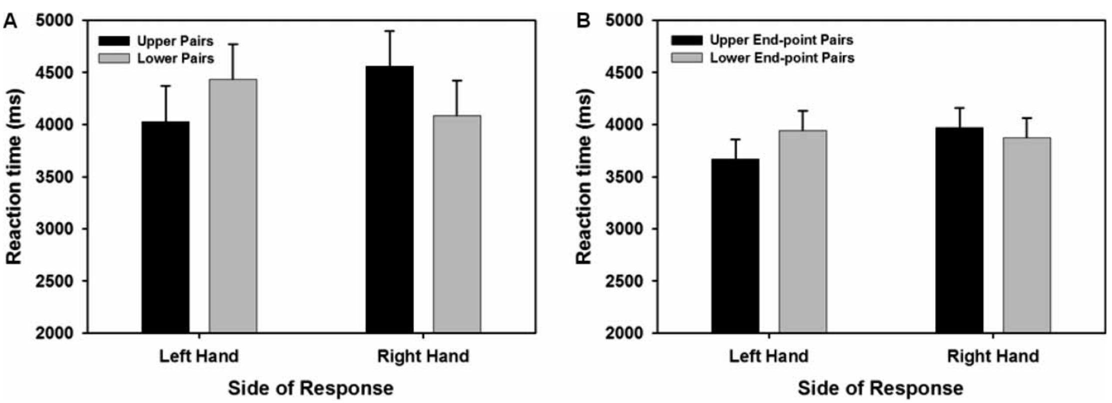

Figure 3. *Experiment 2. (A) Mean correct RTs as a function of side of response (left hand vs. right hand) and position of the pair (upper pairs: AB, BC, AC; lower pairs: AB, BC, AC). (B) Mean correct RTs as a function of side of response (left hand vs. right hand) and position of the end-point pair (upper end-point pairs: AB, AC; lower end-point pairs: EF, DF). Error bars show within-participants 95% confidence intervals.*

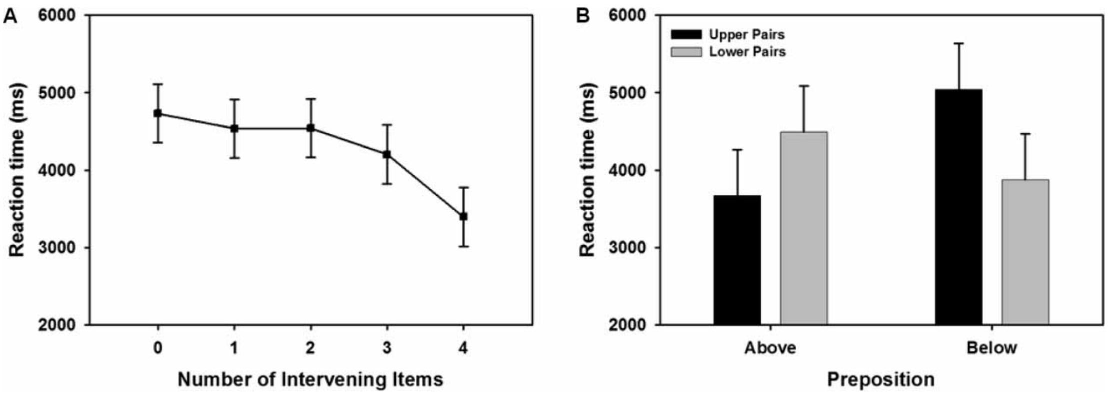

Figure 4. *Experiment 2. (A) Overall mean correct RTs as a function of number of intervening items (0: AB, BC, CD, DE, EF; 1: AC, BD, CE, DF; 2: AD, BE, CF; 3: AE, BF; 4: AF). (B) Mean correct RTs as a function of preposition (above vs. below) and position of the pair (upper pairs: AB, BC, AC; lower pairs: AB, BC, AC). Error bars show within-participants 95% confidence intervals.*

in Experiment 1, no response hand difference was observed on the symmetrical pairs AF, BE, CD (left hand 4,634 ms, right hand 4,935 ms); $t(10) = 0.79$, $p = ns$.

As in Experiment 1, we found a SDE on overall RTs, with a mean RT of 4,731 ms when there was no intervening item, 4,534 ms when 1 intervening item was present, 4,540 ms for 2 intervening items, 4,200 ms for 3 intervening items, and 3,396 ms for 4 intervening items (see Figure 4A). We also observed that upper pairs were evaluated faster than lower pairs with *above* (upper pairs 3,667 ms, lower pairs 4,488 ms), and lower pairs were evaluated faster than upper pairs with *below* (upper pairs 5,040 ms, lower pairs 3,872 ms; Figure 4B).

Taken together, these results indicate the presence of a horizontal SNARC-like effect as in Experiment 1. This suggests that a horizontal representation of the premises is still accessible, even with the prepositions *above* and *below*.

CONCLUSION

Much of the prior evidence for an analogical representation of the premises in relational reasoning comes from the SDE. However, this well-known effect has been shown not to appear in specific circumstances (Sailor & Shobern, 1993; Warner & Griggs, 1980), leaving some unconvinced about the spatial nature of related items in standard relational reasoning problems. In this work, we aimed to show—for the first time as far as we are aware—that a participant's construct of a linear mental representation in a reasoning scenario directly influences an action performed in physical space. Items accessible from the left part of the mental representation are evaluated faster with the left hand whereas items accessible from the right part are evaluated faster with the right hand. This holds when the comparative preposition explicitly encourages a left–right organization (i.e., *to the left/right of*) but also when it did not (i.e., *above/below*). In revealing an *explicit association* between a mental representation and space, this effect provides more direct evidence for an analogical representation of the premises than the SDE can alone. Further, it clearly supports theories that have emphasized the role of visuo-spatial strategies when drawing relational inferences, suggesting that people could rely on mental images (De Soto et al., 1965; Huttenlocher, 1968) or on mental models (Goodwin & Johnson-Laird, 2005; Johnson-Laird, 1983) to resolve such problems.

This effect appears to be analogous to the response-side effect first discovered in numbers (Dehaene et al., 1993) and generalized afterwards to ordinal sequences and pitch height (Gevers, Reynvoet, & Fias, 2003, 2004; Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006). The fact that the same behavioural signatures (i.e., the SDE and the SNARC effect) have now been reported in both relational reasoning and numerical cognition raises the possibility that these competences depend on the same cognitive mechanism, or at least that they rely on the same type of spatial mental representation.

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