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ORIGINAL ARTICLE

Spatial coding of object typical size: evidence for a SNARC-like effect

Roberta Sellaro · Barbara Treccani · Remo Job · Roberto Cubelli

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Abstract The present study aimed to assess whether the representation of the typical size of objects can interact with response position codes in two-choice bimanual tasks, and give rise to a SNARC-like effect (faster responses when the representation of the typical size of the object to which the target stimulus refers corresponds to response side). Participants performed either a magnitude comparison task (in which they were required to judge whether the target was smaller or larger than a reference stimulus; Experiment 1) or a semantic decision task (in which they had to classify the target as belonging to either the category of living or non-living entities; Experiment 2). Target stimuli were pictures or written words referring to either typically large and small animals or inanimate objects. In both tasks, participants responded by pressing a left- or right-side button. Results showed that, regardless of the to-be-performed task (magnitude comparison or semantic decision) and stimulus format (picture or word), left responses were faster when the target represented typically small-sized entities, whereas right responses were faster for typically large-sized entities. These results provide evidence that the information about the typical size of objects is activated even if it is not requested by the task, and are consistent with the idea that objects' typical size is automatically spatially coded, as has been proposed to occur for number magnitudes. In this representation, small objects would be on the left and large objects would be on the right. Alternative interpretations of these results are also discussed.

R. Sellaro and B. Treccani are shared first authors on this work. Co-first authors are listed in alphabetical order.

R. Sellaro
Institute for Psychological Research, Leiden Institute for Brain and Cognition, Leiden University, Leiden, The Netherlands

R. Sellaro (✉)
Cognitive Psychology Unit, Leiden University, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands
e-mail: r.sellaro@fsw.leidenuniv.nl

B. Treccani
Department of History, Human Sciences and Education, University of Sassari, Sassari, Italy

B. Treccani (✉)
Dipartimento di Storia, Scienze dell'Uomo e della Formazione, Università di Sassari, Via Maurizio Zanfarino 62, 07100 Sassari, Italy
e-mail: btreccani@uniss.it

R. Job · R. Cubelli
Department of Psychology and Cognitive Sciences, University of Trento, Trento, Italy

Introduction

Starting from the seminal study of Dehaene, Dupoux and Mehler, (1990), the metaphor of Mental Number Line (MNL; Galton, 1880) has become increasingly popular. Broadly speaking, this metaphor summarizes the idea that numbers are connected to space. Specifically, numbers are thought to be represented on a spatial continuum with small magnitude mapped on the left side and large magnitude mapped on the right (Deheane, 1997). The first demonstration supporting the close link between numbers and space comes from a study by Moyer and Landauer, (1967) who asked participants to decide which of two simultaneously presented numbers was the largest one, by pressing the spatially corresponding button. The authors observed that reaction times (RTs) were influenced by the numerical distance between the two numbers, namely, latencies increased with decreasing numerical distance (e.g., participants took longer to compare 7 and 9 than to compare 3 and 9; i.e., the distance effect). This finding is taken as evidence that the closer two numbers are represented on the MNL, the more difficult the comparison judgments are, and, as such, it would corroborate the hypothesis that numbers are spatially represented. More recently, Dehaene and colleagues (Dehaene et al., 1990; Dehaene, Bossini, & Giraux, 1993; Dehaene, 1997) obtained data suggesting that number representation, besides being spatial in nature, has a specific spatial orientation (i.e., from left to right). Dehaene et al., (1990) provided first evidence for the existence of the so-called SNARC (*Spatial Numerical Association of Response Codes*) effect. They presented participants with a centrally presented digit, randomly ranging from 1 to 9 (excluding the number 5), and asked them to judge whether it was smaller or larger than "5", by pressing a left- and a right-side button (i.e., a magnitude comparison task). Interestingly, the results showed that small numbers (such as 1 or 2) were responded to faster with left-side responses, whereas large numbers (such as 8 or 9) were responded to faster with right-side responses. In a follow-up study, Dehaene et al., (1993) extended these findings by demonstrating that this effect also occurs when the information about number magnitude is completely irrelevant to the task. In this study, participants were required to judge, by pressing either a left- or right-side button, the parity status (odd vs. even) of a centrally-displayed digit (i.e., parity judgment task). Independently of the digit's parity status, number magnitude was found to interact with response position: As observed in magnitude comparison tasks, numerically small numbers primed left-handed responses, whereas numerically large numbers primed right-handed responses. Because number magnitude is irrelevant in the parity judgment task, the occurrence of the SNARC effect in this task is particularly noteworthy: According to Dehaene et al., (1993), this demonstrates that, even when numerical magnitude is irrelevant to the task, an internal (spatial) magnitude representation is nevertheless automatically activated.

Recently, it has been suggested that not only numbers but also other (non-numerical) ordinal sequences are represented in terms of magnitudes, and that the brain can represent information about different magnitudes via a common cognitive/neural mechanism (Walsh, 2003; Cantlon, Platt & Brannon, 2009; Henik, Leibovich, Naparstek, Diesendruck & Rubinsten, 2012[1]). According to this view, the SNARC effect would be an instance of a more general quantity effect, i.e., the SQUARC effect (*Spatial-Quantity Association of Response Codes,* Walsh, 2003). Indeed, SNARC-like effects have also been reported for temporal information (for a review, see Bonato, Zorzi & Umiltà, 2012). For example, participants react faster with the left hand to shorter durations (auditory stimuli lasting for short time intervals) and with the right hand to longer durations (Vallesi, Binns & Shallice, 2008). These results suggest that the left-to-right orientation is not a property restricted to the representation of numbers but also extends to the representation of time, and speak in favor of the idea of a common processing system for different magnitudes (see Gevers, Reynvoet & Fias, 2003, 2004, and Rusconi, Kwan, Giordano, Umiltá & Butterworth, 2006, for evidence of SNARC-like effects with other ordinal sequences; see also Treccani & Umiltà, 2011, for a discussion of the implications of such evidence for the number spatial representation account).

Besides SNARC-like effects, there are other phenomena that are attributable to the spatial coding of stimulus dimensions referring to magnitude. Particularly relevant here are the results of studies suggesting that even the conceptual size of a stimulus (i.e., the typical size of the entity to which a stimulus refers) may be spatially represented. For example, Moyer, (1973) presented participants with pairs of names referring to animals of different sizes and asked them to judge which of the two animals was larger. Consistent with what typically occurs with numbers (Moyer & Landauer, 1967), the results showed that RTs were significantly influenced by the magnitude of the difference between the animals' size, i.e., a *distance effect* was observed (e.g., participants were slower to compare the pair ANT—BEE than the pair ANT—DOG).

In the study by Moyer, (1973), participants were explicitly asked to evaluate object size. However, there are data suggesting that participants may automatically (i.e., without intention) access the information about the typical size of a real-world object when presented with an image or a word referring to that object (e.g., Rubinsten & Henik, 2002; Sereno, O'Donnell & Sereno, 2009; Konkle & Oliva, 2012; Gabay, Leibovich, Henik & Gronau, 2013). For instance, Rubinsten and Henik (2002) asked participants to judge which of two pictures depicting animals was physically larger, while ignoring their conceptual size. Results showed that performance was impaired when the conceptually larger stimulus was the smaller in its physical size (i.e., the *size congruity effect*; see also Paivio, 1975, and Konkle & Oliva, 2012). The same kind of interaction has also been observed between numerical value and physical size of numbers (e.g., Henik & Tzelgov, 1982).

Gabay et al., (2013) required participants to perform the classic numerical parity judgment task, but, in each trial,

[1] It must be underlined that there are data that are inconsistent with the idea of a common processing system for different magnitudes. For example, Leibovich, Diesendruck, Rubinsten, and Henik (2013) obtained results suggesting that the representation of numbers may be different from that of other magnitudes.

the target number was primed by a picture of an animal that was either conceptually small or conceptually large. Although magnitude information was irrelevant to the task, number processing was affected by the conceptual size of the prime stimulus, and a size congruity effect was observed: RTs were faster when the conceptual size of the prime was congruent with the numerical magnitude of the target. These findings, besides demonstrating that the representation of object size is automatically activated, provide further evidence in favor of the assumption that different magnitudes share similar mental representations.

In sum, the available findings indicate that people can extract magnitude information from different stimuli (e.g., numbers, durations, object pictures). Furthermore, there are data suggesting that (a) the access to magnitude information may be automatic (unintentional and mandatory) and may thus occur even if it is not required by the task, (b) the representation of magnitude information is spatial in nature, and (c) different kinds of magnitude information may be represented by a common representational code—specifically, they may be represented on a general magnitude line (MML; cf., Holmes & Lourenco, 2013), using a common left-to-right format. Some types of magnitude information (e.g., numerical information) have been extensively investigated with reference to all these aspects, whereas the picture is still partial with regards to other magnitude dimensions.

The present study specifically focuses on the conceptual size of objects. As previously underlined, prior findings indicate that this magnitude dimension is accessed and represented even when people have to judge another stimulus dimension (e.g., Rubinsten & Henik, 2002). Furthermore, some authors have proposed that size representation, just like the representation of the magnitude of numbers and other quantities, is spatial in nature (Henik et al., 2012). Accordingly, the spatial coding of the conceptual size of objects might be an automatic process and might be comparable to the automatic spatial coding of number magnitude: The analysis of a stimulus (e.g., a word or picture) referring to a given real-world object would necessarily imply the spatial representation of the object typical size and this spatial representation would be similar to that of the number magnitude (in both cases, stimuli would be coded on a general MML).

Following this view, access to objects' conceptual size and its spatial coding would be an unavoidable part of the chain of processes involved in stimulus analysis. Consistent with this idea, one might also postulate that the spatial coding of the typical size is critical in order to access the meaning of the stimulus itself (e.g., Moyer, 1973). Indeed, according to a very influential approach to object recognition, that is, the embodied cognition approach (Barsalou, 1999; Rey, Riou & Versace, 2014), the identification of a given object corresponds to the activation of all stored representations concerning the object: Object identification *is* the activation of object knowledge. The typical size is part of the knowledge of an object and, therefore, the activation of the typical size is part of the process of object identification: An object cannot be identified without its typical size being activated. According to accounts applying this approach to magnitude representation, typical size, like other types of knowledge, is not an abstract, amodal piece of information, but is rather grounded in concrete (spatial) sensorimotor representations (De Simone, 2013), and spatial coding (the coding of an object on the MML) is the way in which magnitude is represented (cf., e.g., Zanolie & Pecher, 2014). Thus, in this scenario the access to typical size *corresponds to* the spatial coding of typical size, and it is pre-categorical, in the sense that it necessarily precedes object identification and has a *functional* role in the identification process. The spatial coding of typical size would also occur when it is not requested by the task, and it would not simply be a concomitant, epiphenomenal effect of identification (cf., Mulatti, Treccani & Job, 2014). The literature about magnitude representation (specifically, data in support of the automaticity of the spatial coding of magnitude information related with a given concept) nicely fits with this hypothesis: Why should participants code a task-irrelevant stimulus dimension such as the typical size of the object to which the stimulus refers if not because it is mandatory (i.e., an automatic process), and why should this process be mandatory if not because it is critical in order to access the stimulus meaning (i.e., it is functionally involved in the identification of the stimulus)?

Our study aimed at complementing previous findings concerning the relation between space and the representation of the conceptual size of objects, and at getting new insights about the nature and role of such a representation. In the first place, we used the typical logic and tools of the literature just described to assess whether effects of objects' conceptual size on RTs could be observed. Furthermore, we intended to evaluate whether these possible effects were consistent with the idea of conceptual size being automatically accessed and spatially represented in a form comparable to the one thought to be used for numbers.

Although it seems that an association exists between objects' typical size and space (Moyer, 1973), evidence that object typical size is automatically represented on a left-to-right oriented MML is lacking. As underlined above, the finding of a SNARC-like effect is usually reckoned as good evidence for a left-to-right spatial representation (Dehaene et al., 1993). As for now, only one study has investigated the existence of a SNARC-like effect for the typical size of objects (Ren, Nicholls, Ma & Chen, 2011; Experiment 4). In this study, participants were successively presented with two central words referring to objects of different sizes, and they were asked to decide whether the second noun referred to an object larger or smaller than the object referred to by the first noun. A SNARC-like effect was observed: responses with the left hand were faster to words referring to small objects, whereas responses with the right hand were faster to words referring to large object. It is important to note that Ren et al., (2011) adopted a direct task (i.e., a magnitude comparison task) that required participants to access explicitly the information about objects' size. Furthermore, the use of a dynamic reference (i.e., a reference that changed each trial) might have further emphasized the relevance of the magnitude information conveyed by the target words. As such, these results do not tell anything about whether the presentation of a stimulus referring to a given object *automatically* evokes a representation of its typical size—data in support of this hypothesis can be obtained only by using an indirect task in which the information about objects typical size is task-irrelevant (i.e., a task similar to the parity judgment task).

In the current study, we verified the existence of a relation between objects' typical size and the side of response execution, in both direct and indirect SNARC-like tasks. In the direct version of the task (Experiment 1), participants were instructed to press a left- vs. a right-side button to decide whether a centrally-presented target stimulus was conceptually larger or smaller than a reference stimulus (i.e., magnitude comparison task). In the indirect version of the task (Experiment 2), participants were instructed to press a left- vs. a right-side button to classify a centrally-presented target stimulus as belonging to the category of living or non-living entities (i.e., semantic decision task). Based on previous evidence suggesting the existence of a relation between objects' typical size and space (Konkle & Oliva, 2012; Rubinsten & Henik, 2002), a SNARC-like effect should be observed at least when the task explicitly requires participants to process the information about object size (i.e., in the magnitude comparison task). This would replicate the findings of Ren et al. (2011). Consistent with the most common interpretation of SNARC-like phenomena (Dehaene et al., 1993), the occurrence of a SNARC-like effect in the semantic decision task, in which the information about objects' typical size is completely irrelevant to the task, would indicate that objects' typical size is automatically and spatially represented, as is the case for numbers' magnitude.

Additionally, for both direct and indirect SNARC-like tasks we manipulated the format of the target stimulus. For half of the participants, pictures of equal size depicting either typically large and small animals or inanimate objects served as target stimuli. For the remaining participants, target stimuli were words referring to these same animals and inanimate objects. The SNARC effect for number magnitude has been shown to occur regardless of the format of the target stimuli (i.e., for both Arabic numbers and number words; e.g., Dehaene et al., 1993; see also Nuerk, Wood, & Willmes, 2005). Consistently, SNARC-like effect for objects' typical size was expected to be independent from the target format. A format-specific effect would imply that such an effect depends on the specific mechanisms involved by the processing of particular stimuli: The magnitude information extracts from pictures is somehow different from that extracted from words, and/or such information interacts differently with response representation.

We also intended to evaluate the time course of the possible SNARC-like effects found in the two experiments by means of RT distribution analyses (RT bin analyses; De Jong, Liang & Lauber, 1994). This could help us to understand whether the processes underling these effects have any role in the stimulus analysis required by the task. The time course of the classic SNARC effect (i.e., the effect usually observed with numbers) has already been investigated. Typically, this effect tends to increase with increasing RTs, and is often not significant at the first bins (i.e., the fastest portion of the RT distribution; Gevers, Verguts, Reynvoet, Caessens & Fias, 2006; Gevers, Ratinckx, De Baene & Fias, 2006; Mapelli, Rusconi & Umiltà, 2003). The finding of such a time course has relevant implications for the significance of number spatial coding in the processing of task-relevant number dimensions.

Indeed, increasing spatial compatibility effects as a function of the lengthening of RT have also been shown with many other types of stimuli, the spatial attribute of which is not physical location (i.e., stimuli whose spatial meaning is not conveyed by their actual position; cf., Treccani, Cubelli, Della Sala & Umiltà, 2009). This has been usually attributed to the fact that the spatial coding of such stimuli takes time (e.g., Ansorge, 2003; Mapelli et al., 2003). When responses are fast, response selection would take place *before* the stimulus is spatially coded (i.e., the correct response is selected on the basis of the task-relevant information before the spatial coding of the stimulus). This clearly implies that, in these tasks, response selection does not critically depend on the spatial coding of the stimulus.

In accordance with this account of RT distributional functions, the pattern of results typically obtained in SNARC tasks suggests that, even if number magnitude is spatially represented regardless of whether it is task-relevant or not, such a spatial coding is not critical for task-relevant operations. People can access information about numbers (and select the correct response) without number magnitude being necessarily spatially represented: At the fastest RT bins, participants show to be able to judge the parity status of the numbers and its magnitude (in parity and magnitude judgment tasks, respectively), even if they have not spatially represented number magnitude yet. Such a finding (at least, following this interpretation) is clearly at odds with the idea of spatial coding of numbers as being at the core of number semantics (cf., Dehaene et al., 1993).

The observation of a similar time course for the space-size association effects in the present study would corroborate the hypothesis that the processing of information about objects' typical size involves the same mechanisms underlying the processing of number magnitude. However, it would also suggest that even if people eventually use space to represent the conceptual size of the target stimulus (i.e., at the slowest bins), they might be able to judge different aspects of the stimulus (the conceptual size itself and/or the semantic category in Experiments 1 and 2, respectively) without (before) such a spatial coding (i.e., at the fastest bins). These results would be inconsistent with an embodied interpretation of conceptual size representation and, in particular, with a pre-categorical account of the role of conceptual size in object recognition (see above): They would indeed suggest that the spatial coding of the conceptual size of a stimulus is not critical to access its semantics.

Such findings might be interpreted in two ways. On the one hand, one might still think that the spatial coding of typical size is an automatic, mandatory, process which, however, does not have any role in object identification: It is simply a by-product of the identification. Yet, the insignificance of the spatial coding of typical size with respect to the recognition process would leave open another possibility. As previously underlined, data suggesting that magnitude information is automatically coded may also suggest that this coding is critical for accessing the information required to perform the task. Conversely, data suggesting that such a coding *is not* critical may also suggest that it is not automatic, mandatory, at all: Why should participants mandatorily code a stimulus dimension if it is not necessary? That is, one might think that the spatial coding of the size of a stimulus does not automatically occur *whenever* the stimulus is perceived, but it is rather due to mechanisms driven by the task-demands (strategic or context- dependent mechanisms; cf., e.g., Zanolie & Pecher, 2014).

Indeed, it is worth noticing that most, if not all, of the findings taken as indicative of automatic coding of magnitude information can actually be re-interpreted as resulting from controlled cognitive strategies used to deal with such information (see, e.g., Fischer, 2006; Lindemann, Abolafia, Pratt & Bekkering, 2008; see also Fischer & Shaki, 2011; Fischer, Riello, Giordano & Rusconi, 2013).

For example, whereas the left–right automatic coding hypothesis is still the most widely-shared account of SNARC-like effects, alternative hypotheses, emphasizing the role of strategic, task-related factors, have also been put forwards (e.g., Van Djick & Fias, 2011)—the polarity account (Proctor and Cho, 2006) is one of the most influential among them. Actually, according to this account, SNARC-like effects result from a type of stimulus coding that, besides being driven by task-related factors, is not even thought to be spatial.

Indeed, effects found in SNARC-like tasks are particularly open to alternative interpretations. Several researchers have argued that SNARC-like effects may be, at least partly, due to response-related activation and representation of stimulus information that, in spite of not being spatial in nature, is mapped to spatial codes because of the structure of the task (cf., e.g., Zanolie & Pecher, 2014; Fischer, 2006). In SNARC-like tasks, participants usually make left/right responses to dichotomous values of the stimulus (e.g., the parity status of a digit—odd vs. even), which creates direct and task-relevant links between stimuli and spatial response codes. The magnitude information conveyed by the stimulus may be similarly coded in a dichotomous abstract format ("small" vs. "large"), which, by virtue of the stimulus–response links, can trigger one of the two relevant spatial response codes. According to these accounts, therefore, SNARC-like effects would not reflect the representation of stimulus magnitude in a visuo-spatial, continuous, analogical format (i.e., the MML), but rather an abstract, symbolic, dicotomous representation (cf., Gevers et al., 2010).

In particular, according to the polarity account, these effects would not originate from the correspondence between the spatial codes of stimulus and responses, but rather from the correspondence between the *verbal* codes assigned to the polarities of stimulus and response dimensions (see also Nuerk, Iversen & Willmes, 2004). SNARC-like effects would simply arise because both large stimuli and right responses are coded as having a positive polarity (they both correspond to the unmarked, dominant pole of the stimulus or response dimension), whereas small stimuli and left responses are coded as having a negative polarity (they both correspond to the marked pole of the stimulus or response dimension). Note that, according to the polarity account, stimulus bipolar coding may require time and is not involve in stimulus recognition: The relationship between the bipolar codes used for stimulus and response dimensions would not then affect the recognition process, which should take place regardless of whether and when the bipolar coding occurs, and should only have an effect on the speed of the choice of the appropriate response among the two alternatives. Data in support of either the spatial or polarity account of the SNARC effect have been collected, but most of the SNARC-like phenomena and their characteristics are compatible with both accounts (cf., Gevers et al., 2010; Imbo, De Brauwer, Fias & Gevers, 2012).

Nevertheless, as noted above, SNARC-like tasks are still considered the tools of choice for assessing whether a certain stimulus attribute is spatially represented on a left-to-right oriented mental line. The finding of a SNARC-like effect for a given stimulus dimension is the starting point for further investigations concerning the nature of the representation of this dimension.

Experiment 1: magnitude comparison task

The aim of Experiment 1 was to verify the presence of a SNARC-like effect for objects' typical size in a task that *explicitly* requires participants to access the information about the typical size of objects they are presented with. To this end, participants performed a magnitude comparison task requiring them to judge whether a centrally-presented target stimulus was conceptually larger or smaller than a reference stimulus, by pressing either a left- or right-side button. Based on previous observations (Ren et al., 2011), we expected the information about the objects' typical size to be activated and to interact with the response position codes. Such an interaction should give rise to a SNARC-like effect, with participants being faster when the representation of the conceptual size of the target stimulus corresponded to the representation of the required response position.

Method

Participants

Fifty-six students (11 males; 2 left-handed; mean age = 21.32) of the University of Trento participated in the study. All participants were naïve regarding the purpose of the experiment and had a normal or correct-to normal vision. Oral informed consent was obtained from each participant.

Apparatus and stimuli

Participants were seated at a viewing distance of 57 cm from a 17-inch monitor screen. Responses were executed by pressing one of two buttons on a QWERTY keyboard. The two buttons were located on the left and on the right of the body midline (the "d" and "l" buttons, respectively) and were operated with the corresponding index finger. Throughout the tasks, both response buttons were marked with white labels. The experiment was run using the E-Prime (Version 1.1.4.1) software system (Psychology Software Tools, Inc., Pittsburgh, PA).

For half of the participants, target stimuli were 24 pictures depicting animals (12 of small size and 12 of large size) and 24 pictures depicting inanimate objects (12 of small size and 12 of large size). For the other half of the participants, targets were the names of these animals and inanimate objects (see Table 1). Target pictures were selected from the sets of Snodgrass and Vanderwart (1980) and Lotto, Dell'Acqua and Job (2001) and presented as black line drawings on a white background. Pictures were of 6 cm either in height or in width. Target pictures that may convey spatial information, resulting from the fact that the depicted object faced left or right, were flipped on the vertical axis. In half of the trials presenting these pictures, the depicted object was shown facing left and in the other half facing right. Target words were presented in black, upper case format, Courier new 24-point bold font. Both pictures and words were presented in the center of the screen.

Procedure

Trials began with the presentation of a fixation cross displayed in the center of the screen. After 700 ms, the fixation cross was replaced by the target stimulus, which remains on the screen until the response but no more than

Table 1 Target stimuli (in alphabetic order) as a function of category (living vs. non living entities) and real-word size (large vs. small)

Living entities		Non-living entities	
Large	Small	Large	Small
Bear [Orso]	Ant [Formica]	Airplane [Aereo]	Ashtray [Posacenere]
Cow [Mucca]	Bee [Ape]	Bridge [Ponte]	Bolt [Bullone]
Deer [Cervo]	Beetle [Scarafaggio]	Bus [Autobus]	Button [Bottone]
Elephant [Elefante]	Caterpillar [Bruco]	Caste [Castello]	Clothes Peg [Molletta]
Giraffe [Giraffa]	Crab [Granchio]	Church [Chiesa]	Key [Chiave]
Gorilla [Gorilla]	Fly [Mosca]	House [Casa]	Light Bulb [Lampadina]
Hippo [Ippopotamo]	Grasshop [Cavalletta]	Hot-Air Balloon [Mongolfiera]	Lipstick [Rossetto]
Horse [Cavallo]	Ladybug [Coccinella]	Lighthouse [Faro]	Nail [Chiodo]
Rhino [Rinoceronte]	Lizard [Lucertola]	Mill [Mulino]	Ring [Anello]
Walrus [Tricheco]	Mouse [Topo]	Ship [Nave]	Staple [Graffetta]
Whale [Balena]	Scorpion [Scorpione]	Train [Treno]	Thimble [Ditale]
Zebra [Zebra]	Snail [Lumaca]	Truck [Camion]	Whistle [Fischietto]

Target words were presented in Italian (in parenthesis)

1,500 ms. Responses were followed by a visual feedback (cf., e.g., Treccani, Milanese & Umiltá, 2010; Pfister, Schroeder & Kunde, 2013) presented for 500 ms in the center of the screen: A green O signaled correct responses, whereas a red O was provided in case of errors (i.e., responses with the wrong button and/or with latencies exceeding 1,500 ms). Finally, a blank interval of 800 ms was presented. Participants were asked to judge, by pressing the left- or right-side button, whether the target stimulus was smaller or larger than a reference stimulus. In the case of animal targets, the reference was a sheep, while, when targets were inanimate objects, the reference was a wardrobe. The instructions emphasized both speed and accuracy. Animals and inanimate objects were presented in separate blocks. Each participant performed four blocks of trials. For each target stimulus category (animals and inanimate objects), there were two blocks of trials. One of these two blocks was composed by spatially corresponding trials: Participants pressed the left button for targets smaller than the reference stimulus and the right button for targets larger than the reference (see Fig. 1—upper panel). The other block was composed of spatially non-corresponding trials: Participants used the left and right buttons for targets larger and smaller than the reference stimulus, respectively (see Fig. 1—lower panel). The order of blocks was counterbalanced as follows. For target category, an ABAB design was adopted, with half of the participants starting with the animal block and the other half starting with the inanimate-object block. For spatial correspondence, an ABBA design was used, with half of the participants starting with the spatially corresponding block and the other half with the non-corresponding block. In each block, each target stimulus was presented twice, which resulted in a total number of 192 trials.

Targets' presentation was randomized. The only restriction was that the same stimulus could not appear in consecutive trials.

Experimental trials were preceded by 8 practice trials in which target stimuli were different from those used in the experimental trials. Familiarization trials were administered before the experimental task to the participants who responded to pictures. That allowed participants to familiarize with the experimental pictures and assured us that all pictures were easily recognizable during the experimental task. In these trials, participants were presented once with all pictures and required to name them. After naming the picture, the picture name was shown on the screen for 1500 ms.

Results

Both mean correct RTs and percentages of errors (PEs) were analyzed. For either each participant or item, the distribution of correct RTs for each target format and level of spatial correspondence was divided into five 20 % bins (De Jong et al., 1994). Mean RTs were computed for each bin.

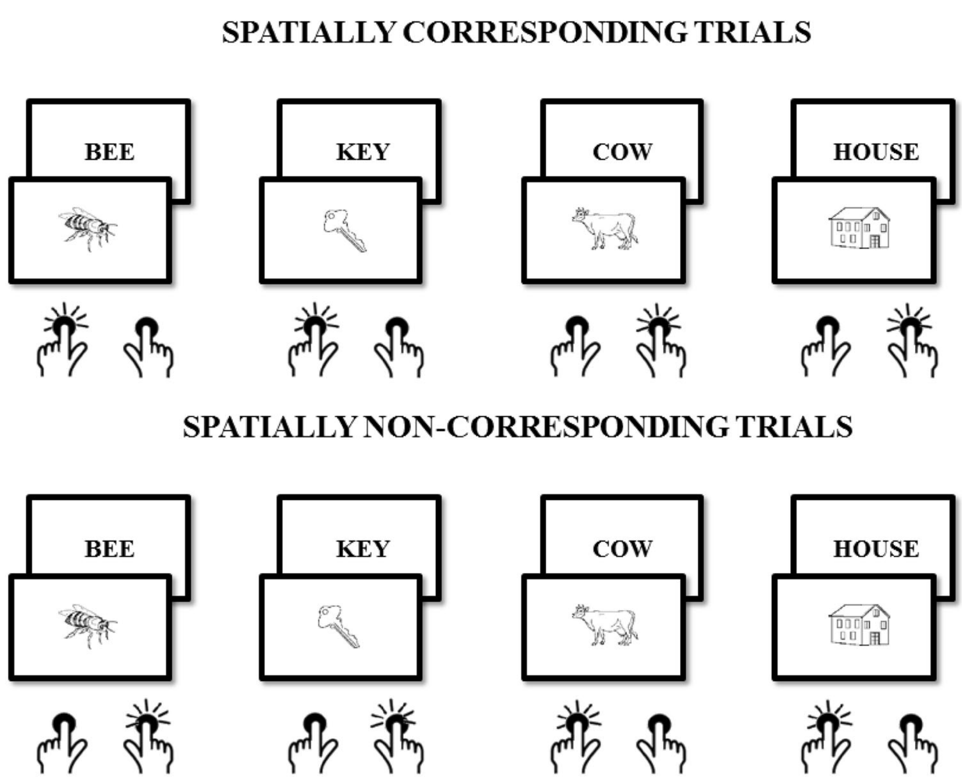

Fig. 1 Examples of spatially corresponding and spatially non-corresponding trials. In spatially corresponding trials (*upper panel*), the response position corresponded the position of the target stimulus in the mental spatial representation of objects' typical size (i.e., small-size targets—left responses and large-size targets—right responses). In spatially non-corresponding trials (*lower panel*), the response position did not correspond to the position of the target stimulus in the mental spatial representation of objects' typical size (i.e., small-size targets—right responses and large-size targets—left responses)

In the by-subject analysis, RTs were submitted to an analysis of variance (ANOVA) with spatial correspondence (spatially corresponding trials vs. spatially non-corresponding trials) and bin (1st–5th) as within-subjects factors and target format as between-subjects factor. PE data were analyzed by means of an ANOVA with spatial correspondence as within-subjects factor and target format as between-subjects factor.

In the by-item analyses, each target (instead of each participant) was treated as a case. RT data were submitted to an ANOVA in which spatial correspondence, target format and bin were all within-items factors. PE data were submitted to an ANOVA with spatial correspondence and target format as within-items factors.

Post-hoc analyses (Newman-Keuls) were performed to analyze further possible significant interactions between factors. F values are reported for both by-subject (F_1) and by-item (F_2) analyses. We used the so-called $F_1 \times F_2$ criterion (e.g., Forster & Dickinson, 1976), according to which the null-hypothesis is rejected only if both by-subject (F_1) and by-item (F_2) ANOVAs show significant F values (both $p_s < 0.05$).

RT analyses revealed, besides the main effect of bin [$F_1(4,216) = 515.381$, $p < 0.001$, $\eta_p^2 = 0.91$, $F_2(4,188) = 3076.24$, $p < 0.001$, $\eta_p^2 = 0.98$], the main effect of spatial correspondence [$F_1(1,54) = 12.04$, $p < 0.005$, $\eta_p^2 = 0.18$, $F_2(1,47) = 91.36$, $p < 0.001$, $\eta_p^2 = 0.66$], with responses faster in corresponding than in non-corresponding trials (586 vs. 606 ms for both the by-subject and by-item analyses), and the main effect of target format [$F_1(1,54) = 18.41$, $p < 0.001$, $\eta_p^2 = 0.25$, $F_2(1,47) = 348.99$, $p < 0.001$, $\eta_p^2 = 0.88$], with responses faster for target-pictures than for target-words (551 vs. 640 ms, and 552 vs. 640 for the by-subject and the by-item analysis, respectively, cf., e.g., Potter & Falconer, 1975). The interaction between spatial correspondence and bin was also significant [$F1(4,216) = 7.45$, $p < 0.001$, $\eta_p^2 = 0.12$, $F2(4,188) = 27.15$, $p < 0.001$, $\eta_p^2 = 0.37$]. Post-hoc analyses (Newman-Keuls) showed that there was no significant difference between non-corresponding and corresponding RTs at the first bin (the differences were 10 ms, $p = 0.054$, and 7 ms, $p = 0.07$, for the by-subject and the by-item analysis, respectively), while significant differences were observed for bins 2–5 ($p_s \leq 0.03$; the differences were 12, 16, 23 and 44 ms in the by-subject analysis and 8, 13, 22, and 53 ms in the by-item analysis; see Fig. 2). A significant interaction between bin and target format was observed in the by-subject analysis [$F_1(4,216) = 3.11$, $p = 0.02$, $\eta_p^2 = 0.05$], but not in the by-item analysis [$F_2(4,188) = 0.25$, $p = 0.91$, $\eta_p^2 = 0.005$]. No other significant sources of variance were found [$F_{1s} \leq 1$, $p_s \geq 0.44$, $F_{2s} \leq 1$, $p_s \geq 0.99$].

For the PE data, no difference was observed between corresponding (3.9 %) and non-corresponding trials (4.1 %) [$F_1 < 1$, $p = 0.76$, $F_2 < 1$, $p = 0.76$]. The main effect of target format (3.4 vs. 4.6 % for target-pictures and target-words, respectively) was significant in the by-item [$F_2(1,47) = 5.54$, $p = 0.02$, $\eta_p^2 = 0.11$], but not in the by-subject analysis [$F_1(1,54) = 2.38$, $p = 0.13$, $\eta_p^2 = 0.04$]. The interaction involving spatial correspondence and format was not significant in either analysis [$F_1 = 1.50$, $p = 0.23$, $F_2 = 1.06$, $p = 0.31$].

Experiment 2: semantic decision task

Experiment 2 aimed at extending the results of Experiment 1 by providing evidence that the presentation of either a picture or word referring to a real-world object automatically evokes a representation of its typical size. To this end, participants performed a semantic decision task requiring them to judge whether a centrally-presented stimulus (a picture or a word) belonged to the category of living or non-living entities, by pressing a left- or right-side button. In this experiment, therefore, the size of the object to which the stimulus referred was completely irrelevant to the task. To the extent to which the SNARC-like effect for objects' typical size resembles the SNARC effect observed for number magnitude, the information about typical size should be represented regardless of whether it is task-relevant. Importantly, the occurrence of a SNARC-like effect in this semantic decision task would provide direct evidence that the information about objects' typical size is automatically accessed and represented in a way that overlaps with the representation of spatial responses.

Method

Participants

A new sample of fifty-six students (19 males; mean age = 21.21) of the University of Trento participated in the study. All participants were naïve regarding the purpose of the experiment and had a normal or correct-to normal vision. Oral informed consents were obtained from all participants.

Apparatus, stimuli and procedure

The apparatus, stimuli and procedure were as in Experiment 1 with the following exceptions. Participants were asked to classify targets as belonging to either the category of living or non-living entities. Half of the participants pressed the left button in response to living entities and the

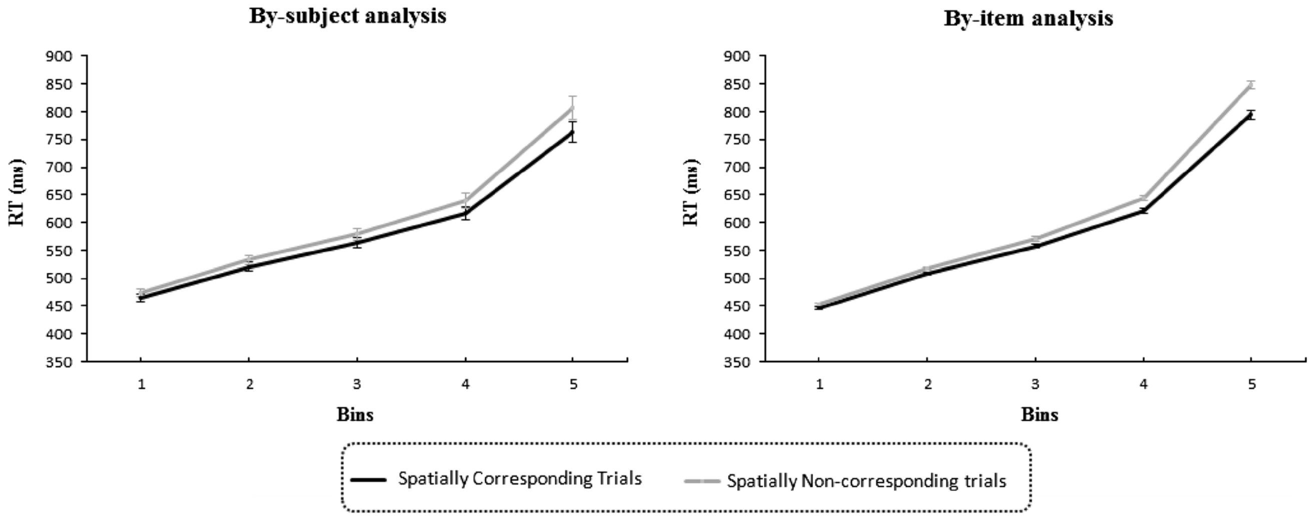

Fig. 2 Means (±SEMs) of correct RTs taken from the by-subject (*left panel*) and the by-item (*right panel*) analyses as a function of spatial correspondence (corresponding trials vs. non-corresponding trials) and bin (1st–5th) in the magnitude comparison task (Experiment 1)

right button in response to non-living entities, whereas the remaining participants received the opposite mapping: They pressed the left button in response to non-living entities and the right button in response to living entities. Trials were divided into two blocks in which each target stimulus was presented twice. In each block, half of the trials were spatially corresponding (i.e., small animals/objects requiring left responses and large animals/objects requiring right responses; see Fig. 1—upper panel) and the other half were spatially non-corresponding (i.e., small animals/objects requiring right responses and large animals/objects requiring left responses; see Fig. 1—lower panel).

Results

RT and PE data were analyzed as in Experiment 1. Results were substantially similar to those obtained in the previous experiment. RT analyses showed significant main effects of bin [$F_1(4,216) = 449.12$, $p < 0.001$, $\eta^2_p = 0.89$, $F_2(4,188) = 3{,}112.19$, $p < 0.001$, $\eta^2_p = 0.99$], target format [$F_1(1,54) = 32.98$, $p < 0.001$, $\eta^2_p = 0.38$, $F_2(1,47) = 246.16$, $p < 0.001$, $\eta^2_p = 0.84$], and spatial correspondence [$F_1(1,54) = 8.26$, $p < 0.01$, $\eta^2_p = 0.13$, $F_2(1,47) = 14.36$, $p < 0.001$, $\eta^2_p = 0.23$]. In general, corresponding trials yielded faster RTs than non-corresponding trials (562 vs. 578 ms, and 561 vs. 578 in the by-subject and by-item analysis, respectively) and responses were faster for target-pictures than for target-words (520 vs. 620 ms, and 518 vs. 620 ms, in the by-subject and by-item analysis, respectively). The interaction between bin and spatial correspondence was significant too [$F_1(4,216) = 5.93$, $p < 0.001$, $\eta^2_p = 0.10$, F_2 $(4,188) = 20.38$, $p < 0.001$, $\eta^2_p = 0.30$]. Post-hoc analyses (Newman-Keuls) revealed that, for the by-subject analysis, the difference between non-corresponding and corresponding trials was not significant at the first bin (6 ms, $p = 0.12$), while significant differences of 10, 15, 19 and 33 ms were observed for bins 2–5, respectively ($p_s \leq 0.02$). For the by-item analysis, the difference between non-corresponding and corresponding trials was not significant at the first three bins (the differences were 3, 7, and 7 ms for bins 1–3, respectively, $p_s \geq 0.09$; see Fig. 3), whereas significant differences of 16 and 49 ms were observed for bins 4 and 5, respectively ($p_s < 0.001$). The by-item analysis yielded three additional sources of variance: two-way interactions involving the factors target format and spatial correspondence [$F_2(1,47) = 8.55, p < 0.01, \eta^2_p = 0.15$], and target format and bin [$F_2(4,188) = 45.99$, $p < 0.001$, $\eta^2_p = 0.49$], and a three-way interactions involving the factors target format, spatial correspondence and bin [$F_2(4,188) = 6.01$, $p < 0.001$, $\eta^2_p = 0.11$]. Importantly, these interactions were not significant in the by-subject analysis [$F_{1s} \leq 2.24, p_s \geq 0.14$].

PE analyses showed no significant difference between corresponding (2.2 %) and non-corresponding trials (2.6 %) [$F_1 < 1$, $p = 0.33$, $F_2 < 1$, $p = 0.33$]. The main effect of target format (3.0 vs. 1.8 % for target-pictures and target-words, respectively) was significant in the by-item [$F_2(1,47) = 9.40, p < 0.005, \eta^2_p = 0.17$], but not in the by-subject analysis [$F_1(1,54) = 2.82$, $p = 0.10$, $\eta^2_p = 0.05$]. The interaction involving spatial correspondence and format was not significant in either analysis [$F_1 = 1.74$, $p = 0.19$, $F_2 = 1.87$, $p = 0.18$].

Discussion

The aim of the present study was to assess whether effects of the typical size of objects on RTs could be observed, and

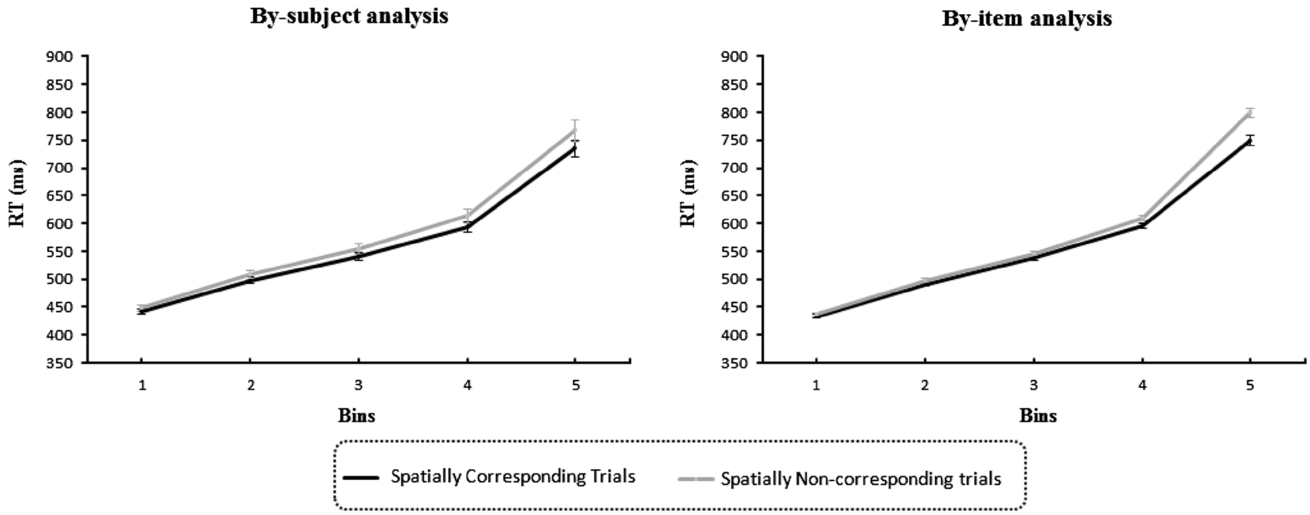

Fig. 3 Means (±SEMs) of correct RTs taken from the by-subject (*left panel*) and the by-item (*right panel*) analyses as a function of spatial correspondence (corresponding trials vs. non-corresponding trials) and bin (1st–5th) in the semantic decision task (Experiment 2)

whether these effects were consistent with the idea of conceptual size information being automatically represented on a left-to-right oriented MML (cf., the SNARC effect; Dehaene et al., 1990). We also intended to analyze in detail these effects (specifically, their time course) in order to get clues about the role of the mechanisms underlying such effects in the stimulus analysis.

To this end, participants were confronted with both direct and indirect SNARC-like tasks, in which target stimuli were pictures and words referring to either typically large and small animals or inanimate objects. In the direct task (Experiment 1), participants had to judge the size of the objects to which target stimuli referred (i.e., a magnitude comparison task). In the indirect task (Experiment 2), the information about objects' typical size was irrelevant and participants had to classify target stimuli according to a living vs. non-living membership (semantic decision task). Consistent with our expectations, we found evidence for a SNARC-like effect in terms of objects' typical size: Participants were faster in spatially corresponding trials (i.e., when the response position corresponded to the alleged position of the target stimulus in the mental spatial representation of objects' typical sizes; e.g., a bee requiring a left-hand response) than in spatially non-corresponding trials (i.e., when the response position did not correspond to the mental spatial representation of the target conceptual size; e.g., a bee requiring a right-hand response). Such a finding corroborates the existence of a relation between objects' typical size and the side of response execution. More specifically, it suggests that the information about objects typical size is represented along a left-to-right orientation, with small objects represented on the left and large objects on the right.

As with the SNARC effect shown for numbers (see e.g., Nuerk et al., 2005), the SNARC-like effects observed here seem to be independent from the target stimulus format. In both Experiments 1 and 2, no differences between the effects found with pictures and words were observed and stimulus format did not interact with any other factor: SNARC-like effects with the same time course occurred regardless of whether participants were presented with pictures or words. The only difference we observed between the two stimulus formats was that, regardless of the to-be-performed task, participants who were presented with pictures responded faster than those who were presented with words. This finding fits with results of prior studies showing that, in tasks requiring access to stimulus semantics, pictures have a processing advantage over words (i.e, the picture superiority effect; e.g., Potter & Falconer, 1975; Hockley, 2008; Mulatti, Lotto, Peressotti & Job, 2010; Goolkasian 1996; Glaser & Glaser, 1989; Kim Guenther, Klatzky & Putnam, 1980; Paivio, 1971, 1975, 1978). Nevertheless, the observed difference between pictures and words in terms of overall RTs did not affect the main findings. This suggests that the (conceptual) magnitude information extracted from the picture of an object is similar to the information extracted from a word referring to the same object and that this information, regardless of its source, triggers a representation of objects' typical size able to interact with response representation in two-choice RT tasks.

As discussed in the 'Introduction', a growing number of studies have showed that when presented with a stimulus referring to an object people can form a mental representation of the object size and that the activation of this representation can produce effects mirroring well-established effects observed within the number domain, such as the distance effect (Moyer, 1973; cf. Moyer & Landauer, 1967) and the size congruency effect (Paivio, 1975; Rubinsten & Henik, 2002, Konkle & Oliva, 2012; Gabay et al., 2013; cf. Henik & Tzelgov, 1982). The results of the present study extend these findings by showing that both pictures and words evoke a mental representation of their size, and that this representation is such that it can produce a SNARC-like effect—another well-known effect observed with numbers (cf. Dehaene et al., 1990, 1993) that has been taken as suggesting that number magnitude is represented along a left-to-right dimension. As such, the present findings corroborate the idea of the existence of a generalized magnitude system that processes indiscriminately several types of magnitude based on a common spatial representation (Walsh, 2003; Canton, Platt, & Brannon, 2009; Henik et al., 2012).

The occurrence of a SNARC-like effect for objects' typical size in the magnitude comparison task replicates recent findings observed by Ren et al. (2011). Such a replication extends the finding of a SNARC-like effect for objects' typical size to a different (and larger) set of stimuli and to a group of participants speaking a different language. Replication is obviously important when using words or pictures as stimuli: It rules out that the results depend on the specific subset of items employed or on the characteristics of the language spoken by participants. However, replication is particularly relevant here: It rules out that the SNARC-like effect for objects' typical size is culture-dependent and/or related to reading habits, which has indeed been proposed for the classic SNARC effect observed with numbers (e.g., Fischer, Mills & Shaki, 2010).

Yet, one of the most important results of the present study is the evidence that the information about objects' typical size was activated even when the task did not require an explicit evaluation of the objects' size, that is, in the semantic decision task. This is consistent with the idea that the objects' size is automatically represented and that the activation of such a representation is not triggered by task instructions. The automaticity of size representation, together with data suggesting that this representation is spatial in nature, are, in turn, consistent with the hypothesis that the spatial frame is automatically activated because it is at the core of the semantics of the stimulus itself (cf., e.g., Treccani & Umiltà, 2011; De Simone, 2013). However, some additional results were obtained here that could soften these conclusions.

The time course of the effects observed here mirrors the typical time course of the SNARC effect, which has been found to increase with increasing RTs (Gevers et al., 2006a, b; Mapelli et al., 2003). Indeed, in both experiments we observed more pronounced and reliable effects for slower responses: The effects were absent at the first bin(s) and present at the latest ones. This suggests that the mechanisms underlying the effects observed here are similar to those underlying the classic SNARC effect.

As previously underlined, increasing spatial-compatibility effect functions across RT bins have been usually attributed to the fact that, at the fastest bins (i.e., when RTs are very short), the stimulus has not been spatially coded yet. That would happen when spatial coding takes longer compared to when people code the physical position of the stimulus. Therefore, for some responses (the fastest ones), response selection may take place *before* stimulus spatial coding (cf., Treccani et al., 2009). Accordingly, the pattern of results obtained here suggests that, even if (eventually) the typical size of an object is spatially represented regardless of whether it is task-relevant or not, semantics of the object (Experiment 2) and information about its typical size (Experiment 1) can be accessed without the objects' conceptual size being necessarily spatially coded: At the fastest bins, participants showed to be able to judge the stimulus semantic category and its size with respect to the size of another stimulus even if they have not (yet) spatially represented the stimulus size. These findings are not consistent with an account assigning to the spatial coding of size a functional role in object recognition (a 'pre-categorical' account—cf., Mulatti et al., 2014—of the spatial coding of size, which posits that there is no object recognition without such a coding). As previously underlined, a longstanding debate concerning magnitude spatial representation is whether this spatial representation is automatically triggered as an intrinsic part of the semantics of the stimulus or it is a short-term representation built up during the execution of the task (van Dijck & Fias, 2011). Data suggesting that the spatial coding of the conceptual size of a stimulus is not critical to access its semantics appear to favor the latter option. That is, these findings might lead one to think that spatial coding of objects' typical size, far from being automatic and mandatory, is due to strategic, task-driven mechanisms.[2]

This alternative interpretation obviously also applies to other SNARC-like effects. Notably, it counts even when considering domains in which the idea of an automatic link with space is reckoned to be well-established, that is, the number domain (cf., Santens & Gevers, 2008; Gevers et al.,

[2] The finding that the spatial representation of conceptual size is not functionally involved in magnitude comparison and semantic decision (i.e., broadly speaking, in object recognition) does not rule out that spatial coding occurs automatically. One may still think that magnitude spatial representation is a mandatory process. However, such a process, having no role in object recognition, may appear epiphenomenal in nature, that is, this finding would undermine the hypothesis according to which space is a core feature of magnitude representation (or, more in general, of stimulus semantics).

2010). Indeed, as pointed out in the 'Introduction', most of the findings taken as indicative of the automatic spatial coding of numbers can actually be re-interpreted as resulting from strategic processes (see, e.g., Fischer, 2006; Zanolie & Pecher, 2014). The hypothesis according to which space is a key feature of the cognitive representation of magnitude (and, as such, it is mandatorily activated when stimuli with different magnitude values are presented) is still the dominant explanation of SNARC-like phenomena. However, many alternative accounts, emphasizing the role of strategic, context-dependent/task-related, factors, have also been put forwards (e.g., the working-memory account, Van Djick & Fias, 2011, and the polarity account, Proctor and Cho, 2006; Nuerk et al., 2004).

Results of the present study can be accounted for by these alternative interpretations too. These accounts propose that the stimulus representations giving rise to SNARC-like effects (i.e., either spatial or verbal temporary codes) are constructed during task execution and thus would not be inherently associated to magnitude. Yet, as has been pointed out in several previous papers (e.g., Treccani & Umiltà, 2011), it is undeniable that humans (and not only humans; e.g., Adachi, 2014) exhibit a particular proneness to, and predilection for, associating spatial positions with magnitudes, rather than with other stimulus dimensions. This speaks in favor of a unique and special relation between magnitude and space. In accordance with this view, the present results indicate that there exists a close link between size, number and space representations, whatever its nature may be. Irrespective of the nature (automatic vs. strategic) of the magnitude representation yielding the spatial effects observed in different SNARC-like tasks, the similarity between the effects obtained with different magnitudes (e.g. number magnitude and object size) are suggestive of a common coding system which overlaps with the way space is coded.

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