Beyond fixed sets: Boundary conditions for obtaining SNARC-like effects with continuous semantic magnitudes

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Abstract

Previous research has demonstrated the presence of an effect (i.e., the spatial-numerical association of response codes or SNARC) in both numerical parity and magnitude judgment tasks in which smaller numerical magnitudes are manually responded to faster on the left side and larger numerical magnitudes on the right side. Such a result has typically been attributed to a spatially based representation of numerical magnitude in long-term memory, the format of which has recently been postulated to be positional in line with learning of a canonically ordered number sequence. As a test of this view, in the current research, participants made classification judgments involving either the size \((N = 88)\) or the living-nonliving status \((N = 114)\) corresponding to the names of animals/objects etc. (for which no learned canonical ordering of size exists). Names were taken from a very large set of 400 animals/objects etc. and each name was presented only once in an experimental session. Responses were made using left and right manual keypresses. The lack of any differential performance effects in response time (or accuracy) involving the relative sizes of the animals/objects and the side of response in this current work indicated that SNARC-like effects do not seem to occur under conditions in which the use of positional coding of size in either long- or short-term memory is precluded.

Introduction

Twelve years ago, an interesting and extremely theoretically relevant spatial compatibility effect was demonstrated by van Dijck and Fias (2011). They had participants hold small sets of randomly ordered digits in short-term working memory (WM) to which parity judgments had to be made whenever one of the digits from the set was presented within a stream of digit trials (with parity responses to be withheld otherwise). They found that manual responses made to the left and right sides were differentially speeded by the positions of the digits within the memory set. Digits that were closer to the beginning of the set were responded to faster with the left response key and digits that were closer to the end of the set were responded to faster with the right response key. Such an effect was referred to as an ordinal position effect by van Dijck and Fias (2011) and was highly suggestive of a left-to-right positional representation of the digit sequence in WM.

The key relevance of such an effect was its similarity to the classic spatial-numerical association of response codes (SNARC) effect. As has been demonstrated many times, numbers of smaller magnitude are seemingly associated with the left side of space and numbers of larger magnitude with the right side of space (Fischer & Shaki, 2014). This effect was first demonstrated by Dehaene and colleagues (Deheane et al., 1993; Deheane et al., 1990) who found that when making numerical judgments involving either parity or magnitude, manual responding to numbers that were smaller in magnitude with respect to the set of numbers under consideration was faster on the left than the right side with the reverse being true for larger numbers. Such findings led them to conclude that numbers are represented in long-term, semantic memory on “a mental number line ... [that] bears a natural and seemingly irrepressible correspondence with the left-right coordinates of external space” (Dehaene et al., 1993, p. 394). Although still remaining a key account for the SNARC effect (Fischer & Shaki, 2014),
subsequent work has also been done to address the possibility that it is correspondences between categorical (as opposed to visuospatial) codings of small-large number magnitude and left-right response locations that underlies the emergence of this effect (Gevers et al., 2010; Proctor & Xiong, 2015).

One very intriguing ramification of the ordinal position effect observed by van Dijck and Fias (2011) was that it raised the possibility that the SNARC effect, in general, might also be arising out of temporary positional representations of numbers in WM. Such a WM account for the SNARC effect could then go a long way towards accounting for the great deal of flexibility in the manifestation of this effect that has been demonstrated over the years (van Dijck & Fias, 2011). Moreover, in van Dijck and Fias (2011)’s study, the ordinal position effects they found were not accompanied by SNARC effects implying that filling up WM with the digit memory set then precluded the SNARC effect itself from occurring.

Nonetheless, subsequent empirical work performed to determine the boundary conditions underlying van Dijck and Fias (2011)’s findings ended up motivating the notion that both temporary position-space associations in short-term memory and more stable pre-existing position-space associations in long-term memory (akin to Dehaene et al.’s, 1993, notion of a mental number line) can influence responding to numerical tasks and lead to compatibility effects (with the latter associations arising out of a learned representation of the number sequence in its canonical order that is currently activated due to its relevance to the task at hand). Namely, Ginsburg et al. (2014) found that requiring parity responses to all numbers, not just the ones in the memory set, resulted in a reappearance of the SNARC effect and elimination of the ordinal position effect. In addition, both this result and van Dijck and Fias (2011)’s original result were also replicated by Ginsberg et al. (2014) with a magnitude comparison task (i.e., is the presented digit smaller or larger than 5?) in place of the parity task. Next, Ginsburg and Gevers (2015) managed to obtain both ordinal position and SNARC effects simultaneously by having participants switch back and forth between conditions which they had to respond only to digits in the memory set and conditions in which they had to respond to all presented digits. Next, in a further replication of van Dijck and Fias (2011)’s original results, Huber et al. (2016) showed that the use of the number sequence 1 – 10 (as in van Dijck & Fias, 2011) actually serves to attenuate the SNARC effect, but not the ordinal position effect, compared to when the number sequence 1 – 9 only is used in which case both effects are present even in the original van Dijck and Fias, (2011) response conditions.

The focus of the current work is on the nature of the long-term representation underlying the SNARC effect. The view arising from the research reviewed above is that the SNARC effect reflects spatial associations linked to the long-term representation of the numerical sequence in its canonical order (i.e., from the activation of pre-existing positions in long-term memory; Ginsburg & Gevers, 2015). The fact that this long-term representation was then assumed to be positional was presumably due to the fact that the WM version of this spatial-compatibility effect (i.e., the ordinal position effect) was necessarily positional-based. Hence, the possibility that the corresponding long-term version of this effect (i.e., the SNARC effect) was also positional-based just makes sense. To test this assumption, though, would require the use of an alternative form of symbolic stimuli whose underlying magnitude representation does not correspond to a learned canonical sequence.
One example of just such a case would be the conceptual magnitudes (i.e., typical sizes) corresponding to the names of animals/objects. In this vein, there are two studies that have examined the spatial characteristics associated with such conceptual magnitudes. First, Ren et al. (2011; Experiment 4) had participants judge whether the second of two presented object names referred to an object that was smaller or larger than the first. Computer key responses were made using the left and right index fingers with the mapping of the smaller and larger responses to each response side reversed halfway through the experimental session and the order of use of the mappings counterbalanced across participants. All stimuli were taken from a nine names throughout (i.e., dust, bean, eraser, apple, volleyball, table, plane, and mountain). Responses with the left hand were faster to smaller objects and, similarly, for right-hand responses to larger objects.

Second, Sellaro et al. (2015; Experiment 1) had participants judge whether presented names referred to an object that was smaller or larger than a sheep (for animal names) or a wardrobe (for object names) by pressing a left- or right-side response button (again with the response mapping reversed within participants and counterbalanced across participants). Another group of participants repeated the task with line-drawings as stimuli instead of names. Twelve small animals (e.g., mouse) and 12 large ones (e.g., hippo) were used along with 12 small inanimate objects (e.g., ring) and 12 large ones (e.g., truck). Sellaro et al. (2015) found that spatially corresponding trials (i.e., small entities responded to on the left and larger entities responded to on the right) were faster than spatially non-corresponding ones (i.e., large entities responded to on the left and small entities responded to on the right). They also went on to replicate this effect in the responding to a semantic decision task involving these same stimuli. In that task, participants had to indicate whether the presented stimulus represented either a living or nonliving thing. Such conditions have typically been regarded as allowing for a determination of whether size information along with its corresponding spatial component is automatically accessed.

Both sets of researchers concluded that their results could be regarded as supporting the notion of a common magnitude representation in the brain (e.g., intra-parietal sulcus) in line with the notion of a more general spatial-quantity association of responses codes (SQUARC) that was originally proposed by Walsh (2003; Macnamara et al., 2018). One problem with such a conjecture, though, is that the stimulus sets used by both Ren et al. (2011) and Sellaro et al. (2015) involved a finite set of items that were repeatedly presented throughout the course of the experimental sessions. As such, the possibility that the stimuli used indeed ended up being represented positionally in WM during the performance of each of these tasks cannot specifically then be ruled out.

Hence, in the current study, both smaller-larger and living-nonliving judgments were made with respect to a very large set of 400 animals/objects etc. whose names were each presented only once during the course of the experimental session. Such stimulus presentation conditions can then be regarded as sampling from a potentially “infinite” stimulus set. Given that it is highly unlikely that the full semantic continuum of such sizes is represented in terms of an ordered positional array (Shoben et al., 1989) any observed spatial compatibility relations between the sizes of the stimuli and the side of response cannot then be positional based, hence, supporting the presence of SQUARC. Contrastingly, the
lack of any such spatial compatibility relations for such stimulus presentation conditions would suggest that a positional representation of magnitude arising from the canonical ordering of number sequences is a necessary requirement for the elicitation of the SNARC effect.

Moreover, the results of the current study also have important ramifications for an extended theoretical development of the WM account postulated by Abrahamse, van Dijck, and Fias (2016). In this revamped account, a long-term canonically ordered representation of the number sequence is still assumed. However, the items in it can only become cast in spatial terms when their task-relevancy causes them to be bound to one of a number of possible co-existing spatial templates in WM (i.e., the long-term memory representation itself does not contain any spatial aspects). At that point, “spatial codes are generated from referential coding processes that are at play when a currently presented item is matched to the active spatially defined ‘set template’” (Abrahamse et al., 2016, p. 5). Hence, as in the current study, if the possibility of establishing a temporary representation of the stimulus set in WM is precluded by not using finite set of items, then the WM account of Abrahamse et al. (2016) would surely predict that no SNARC effect should occur.

**Experiment 1**

**Methods**

**Participants**

Ninety-eight students from Carleton University participated in the study (68 females, 22 males, 4 other, and 4 not disclosed) where the size of this sample is three-to-four times larger than the typical sample used to study SNARC effects in the past. The average age was 21.0 years \( (SD = 3.40 \text{ years, range: 17–45 years}) \) and 91 of the participants were right-handed (with 2 left-handed and 5 ambidextrous). Seventy-eight participants self-reported as being native English speakers with the remaining 20 claiming full proficiency in English. Of those participants, 5 were Middle-Eastern, 9 were Asian/Chinese, 3 were European/Caucasian, 1 was Latino, and 2 did not disclose. The study was approved by Carleton University Ethics committee. All participants were students in Introductory Psychology and Methods and were rewarded .5% course credit for participating in this study. There were no exclusion criteria for recruitment.

**Stimuli and Apparatus**

The study was run online using experimental software programmed in Gorilla (a cloud software platform specifically for the behavioural sciences; Anwyl-Irvine et al., 2019). Stimuli were 420 names taken from a set of size norms for 576 animals/objects etc. developed by Shoben et al. (1989). These norm values range from −8.875 for “Bacteria” to 8.804 for “Dinosaur” and the 420 name stimuli used for the present study were drawn evenly across this range by attempting to choose those that were most likely to be familiar to the participants (e.g., with names like Silkworm and Belfry regarded by the authors as likely to be unfamiliar). The full stimulus set is provided in the Appendix.
Procedure

At the beginning of the experiment, participants were given a link to do the experiment online. First, informed consent was given and the participants were instructed to click on a button to give their consent to continue. Next, they were asked to indicate their gender, age, handedness, and also whether English is their first language. They were then asked to complete four blocks of 100 experimental trials along with two practice blocks of 10 trials (one before Block 1 and the other before Block 3). The names used in each of Blocks 1, 2, 3, and 4 (and the corresponding practice blocks) were kept the same for all participants but were randomized differently within each block for each participant. Each name was presented in the center of the computer screen in standard font (with the first letter capitalized) and used only once during the experimental session.

Over the first two blocks, half of the participants were instructed to press the “Q” key on the computer keyboard with their left index finger if the presented name referred to something that was smaller than a “chicken” or otherwise press the key “P” with their right index finger if the presented name referred to something that was larger than a "chicken". This reference had a normed size value of -1.16 that was very close to the middle of the set of normed values given the presence of slightly more negative then positive values in that set. For the last two blocks, the previous mapping of smaller and larger things to left and right keys was reversed (with the order of these mappings counterbalanced across participants). Each trial started with a blank screen for 2 seconds, followed by the presentation of the name, followed by a manual response (at which point the name disappeared). Participants were asked to respond as quickly as possible while still trying to stay accurate. They were given the opportunity to take breaks between each block and at the end of the four blocks participants were given a debriefing sheet. The whole study took about 30 minutes to perform.

Results

Data was collected from 98 participants, some of whom responded with the mapping of left-smaller and right-larger in the first two blocks which was then switched in the last two blocks. The others started off with the left-larger and right-smaller response mapping and then switched to the reverse mapping in the last two blocks. No data from practice trials was used. One participant was dropped for making a third of their responses before 200 ms and nine more were dropped for having an accuracy rate below 60% (42%, 47%, 47%, 51%, 50%, 52%, 56%, 56%, and 59%, respectively) leaving 45 and 43 participants for each mapping order, respectively. For the remaining 88 participants, two had accuracy rates between 65–69%, two had accuracy rates between 70–74%, and five had accuracy rates between 75–79%. The mean accuracy rate for these 88 participants was 88%. 35,200 RTs were collected from these participants (88 participants x 400 trials). 870 RTs (2.5%) were initially cut for being either below 200 ms or above 7 seconds (with 5 and 10 seconds also having been considered but deemed by the authors to be too strict and too lenient, respectively). 3,926 more RTs (11.2%) for incorrect responses were then also cut. Finally,
696 of the remaining RTs (2.0%) that were outside the interval ± 3 SD around each participant’s mean RT were further trimmed.

A mixed regression model with participants as a random factor was run in SPSS on the trimmed raw RT data (all of the data and syntax for these analyses can be found at https://osf.io/7pkst/?view_only=14cf067b0ff34534bdffab3dd4d14cf5). For this analysis, side of response was dummy coded as 0 for left-hand responses and 1 for right-hand responses. The Shoben et al. (1989) normed sizes values corresponding to each stimulus were used as the size predictor with the cross-multiplied interaction of response side and size also added to the regression model. For such an analysis, the regression coefficient for response side indexes the overall RT difference between the right and left sides. The coefficient for size indexes the linear relation between size values and RTs for left-hand responses with the coefficient for the interaction indicating how much the slope of this relation changes for right-hand responses. If smaller stimuli are responded to faster with the left hand than are larger stimuli, the size coefficient should be positive. If this relation switches for right hand responses the corresponding slope and, therefore, the coefficient for the interaction should be negative. Hence, a significant interaction term signals a significant SNARC-like effect. In this analysis, however, the coefficient for response side was not significant ($b = -9.77$ [95% C.I: -27.40, 7.85], $t = -1.10$, $p < .273$), the coefficient for size was not significant ($b = 2.69$ [95% C.I: -1.17, 6.56], $t = 1.39$, $p < .169$), and the coefficient for the interaction was also not significant ($b = -5.15$ [95% C.I: -11.55, 1.24], $t = -1.60$, $p < .113$). Figure 1 plots the relation between both left-side and right-side mean RTs (i.e., averaged over participants) with size.

In order to determine whether these relations were consistent for each mapping order, it was effect coded as −.5 for the small-left/large-right first order and .5 for the large-left/small-right first order. This variable was then added to the mixed regression model along with the interactions corresponding to its cross-multiplication with each of the other three variables (response side, size, and their two-way interaction). In this analysis, mapping order interacted with size ($b = -9.79$ [95% C.I: -17.32, -2.26], $t = -2.58$, $p < .011$) indicating that the slope of the relation between size and RT for left-handed responses differed across mapping orders. As well, it also interacted with both size and response side ($b = 14.53$ [95% C.I: 1.99, 27.07], $t = 2.31$, $p < .024$) indicating that the change in the slope of the relation between size and RT for right-handed responses in comparison to left-handed responses differed across mapping orders. Namely, for the small-left/large-right first mapping order the slope of the relation between size and correct RT was $b = 7.57$ for left-hand responses and $b = -4.93$ for right-hand responses. On the other hand, for the large-left/small-right first mapping order the slope of the relation between size and correct RT was $b = -2.36$ for left-hand responses and $b = -0.21$ for right-hand responses.

To corroborate this result, regressions for each individual separately were then run with RT as the outcome variable and response hand, size rating, and their interaction as the predictors Note that because each stimulus was only presented once in a session it was not possible to obtain right hand minus left hand difference RTs (but if they could have been obtained and were regressed against size directly that slope would have had the same value as the coefficient for the above response hand by size interaction). Interaction coefficient values from these regressions for each participant were entered in an SPSS data
A one sample $t$-test was then run on these interaction coefficient values to determine whether their mean of -5.26 differed from 0. It did not ($t[87] = -1.35, p < .179, d = -0.14, BF_{01} = 3.52$; with the Bayes Factor computed from http://pcl.missouri.edu/bf-one-sample).

However, an examination of the individual coefficients revealed one with a value of -189.9 that turned out to be more than 5.05 SDs below the mean and, hence, could absolutely be regarded as an outlying coefficient value (with this individual having done the small-left, large-right mapping order first). When this value is omitted and the one sample $t$-test analysis re-ran, the mean interaction coefficient value is now $-3.14$ ($t[86] = -0.95, p < .343, d = -0.10, BF_{01} = 5.49$). Moreover, when the linear mixed model mentioned above was re-ran with this participant omitted, the coefficient for response side was again not significant (with $b = -8.19$ [95% C.I: -25.81, 9.42], $t = -0.93, p < .358$), the coefficient for size was again not significant (with $b = 1.58$ [95% C.I: -1.63, 4.79], $t = 0.98, p < .332$), and the coefficient for the interaction was again also not significant (with $b = -3.03$ [95% C.I: -8.08, 2.02], $t = -1.19, p < .236$). For the small-left/large-right first mapping order, the slope of the relation between size and correct RT was reduced to $b = 5.43$ for left-hand responses and $b = -2.93$ for right-hand responses by omitting this participant.

**Discussion**

When judging the sizes of animals, objects, etc. taken from a large “infinite” set whose names were each presented only once during the course of the experimental session, the response hand by stimulus size regression coefficient signaling the presence of a potential SNARC-like association effect between size and left-right responding was not significant. As discussed earlier, if it had been significant, doubt would have been cast on the positional-based underpinnings of the SNARC effect given that the long-term conceptual representation of the sizes of such stimuli is not likely to be positional in nature. Moreover, the fact that each stimulus was presented only once was not very amenable to the formation of a temporary positional-based representation of the sizes of the stimuli in WM. Hence, the lack of a SNARC effect in the current Experiment 1 affords the conclusion that SNARC is indeed likely to be positional based because such an effect does not seem to occur under conditions for which the possibility of an underlying positional-based long- or short-term memory representation of stimuli size is precluded. As also discussed earlier, such a finding would also be consistent with the view of Abrahamse et al. (2016) who assume that SNARC effects arise from a mapping of ordered numerical magnitude information from long-term memory onto temporary spatial templates in working memory.

**Experiment 2**

Before settling on such a conclusion, however, a replication of the Experiment 1 results is in order. As well, an important potential issue with those results is that, in single-digit magnitude comparisons, spatial-numerical compatibility is actually confounded with the response mapping being used in a block. Namely, blocks that require the small-left and large-right response mapping are necessarily spatially compatible blocks and those that require the large-left and small-right response mapping are necessarily
spatially incompatible blocks. Such a fact then necessitates a fairly even counterbalancing of the order of the response mapping used first and second to ensure that the SNARC effect is not confounded by the order in which the spatially compatible and incompatible response mappings are performed. Indeed, in Experiment 1, SNARC-like effects did seem to be evident for those participants who performed the spatially compatible mapping first (i.e., an overall positive relation between size and RT for left responses and negative relation for right responses). On the other hand, such effects were not evident for those who performed the spatially incompatible mapping first (hence, the need to counterbalance the mapping order).

In this second experiment, a replication of the previous result was run. For this replication, however, the task was changed to require living versus nonliving judgments. Given that size information is irrelevant for such judgments, the current task could be regarded as being analogous to the use of the parity task to study the SNARC effect in numerical comparisons. In such work, SNARC effects are typically very robust. Hence, it is actually quite important to determine whether or not SNARC-like effects might appear here under conditions in which magnitude information is an implicit as opposed to an explicit aspect of the task. As well, although response mapping order will still be examined (and counterbalanced across participants), the response mappings for such a task are not confounded with spatial compatibility which then ameliorates the mapping order issue mentioned above.

**Methods**

**Participants**

One hundred and twenty four students from Carleton University participated in the study (82 females, 39 males, and 3 other) under the same conditions as the previous experiment. The average age was 20.0 years ($SD = 3.79$ years, range: 18–43 years) and 106 of the participants were right-handed (with 17 left-handed and 1 not disclosed). Eighty-eight participants self-reported as being native English speakers with 30 more claiming full proficiency in English and 4 claiming to be somewhat proficient (unfortunately, no ethnicity data was collected for this experiment).

**Stimuli and Apparatus**

The study was again run online using experimental software programmed in Gorilla (Anwyl-Irvine et al., 2019). Stimuli were the same 420 names as in Experiment 1.

**Procedure**

The procedure was the same as in Experiment 1 except for the fact that participants were asked to decide whether the name presented on the screen now represented either a living thing (i.e., animal, fruit, vegetable, or plant) or a nonliving thing (i.e., object, vehicle, structure). Over the first two blocks, half of the participants were instructed to press the “Q” key on the computer keyboard with their left index finger if the presented name referred to a living thing otherwise they should press the key “P” with their right index
finger if the presented name referred to a nonliving thing. For the last two blocks, the previous mapping of living and nonliving things to left and right keys was reversed (with the order of these mappings counterbalanced across participants).

**Results**

Data was collected from 124 participants, some of whom responded with the mapping of left-living and right-nonliving in the first two blocks and switched it in the last two blocks. The others started off with the left-nonliving and right-living response mapping. No data from practice trials was used. Two participants were dropped for having mean RTs more than 3 SDs above the mean of the other participants and eight more participants were dropped for having an accuracy rate below 60% (11%, 47%, 47%, 48%, 49%, 49%, 52%, and 55%, respectively) leaving 60 and 54 participants for each mapping order, respectively (due to a bit of a participant sign-up rush at the end of one of the terms, a few more ended up being collected for the left-living and right-nonliving response first mapping order). For the remaining 114 participants, three had accuracy rates of 64%, 66%, and 77% with the rest having rates above 80%. The mean accuracy rate for these 114 participants was 93%. 45,600 RTs were collected from these participants (114 participants x 400 trials). 1,112 RTs (2.4%) were initially cut for being either below 200 ms or above 7 seconds. 2,885 more RTs (6.3%) for remaining incorrect responses were then also cut. Finally, 896 of the remaining RTs (2.0%) that were outside the interval ± 3 SD around each participant's mean RT were further trimmed.

As before, a mixed regression model with participants as a random factor was run in SPSS on the trimmed raw RT data (see https://osf.io/7pkst/?view_only=14cf067b0ff34534bdfab3dd4d14cf5 for the data and syntax). For this analysis, side of response was dummy coded as 0 for left-hand responses and 1 for right-hand responses. The Shoben et al. (1989) normed sizes values corresponding to each stimulus were used as the size predictor with the cross-multiplied interaction of response side and size also added to the regression model. Once again, for such an analysis, the regression coefficient for response side indexes the overall RT difference between the right and left sides. The coefficient for size indexes the linear relation between size values and RTs for left-hand responses with the coefficient for the interaction indicating how much the slope of this relation changes for right-hand responses. If smaller stimuli are responded to faster with the left hand than are larger stimuli, the size coefficient should be positive. If this relation switches for right hand responses the corresponding slope and, therefore, the coefficient for the interaction should be negative. Hence, a significant interaction term signals a significant SNARC-like effect. In this analysis, the coefficient for response side was not significant ($b = -4.72$ [95% C. I.: -17.36, 7.92], $t = -0.74$, $p < .461$), the coefficient for size was significant ($b = -3.46$ [95% C. I.: -4.77, -2.14], $t = -5.17$, $p < .001$), but the coefficient for the interaction was not significant ($b = 0.68$ [95% C. I.: -1.19, 2.55], $t = 0.72$, $p < .472$). Figure 2 plots the relation between both left-side and right-side mean RTs (i.e., averaged over participants) with size.

In order to determine whether these relations were consistent for each mapping order, it was effect coded as − .5 for the small-left/large-right first order and .5 for the large-left/small-right first order as before. This
variable was added to the mixed regression model along with the interactions corresponding to its cross-multiplication with each of the other three variables (response side, size, and their two-way interaction). In this analysis, mapping order interacted with both size and response side ($b = 3.84$ [95% C. I.: 0.13, 7.55], $t = 2.04, p < .043$) indicating that the change in the slope of the relation between size and RT for right-handed responses in comparison to left-handed responses differed across mapping orders. Namely, for the left-living/right-nonliving first mapping order the slope of the relation between size and correct RT was $b = -2.81$ for left-hand responses and $b = -3.88$ for right-hand responses. On the other hand, for the left-nonliving/right-living first mapping order the slope of the relation between size and correct RT was $b = -4.19$ for left-hand responses and $b = -1.49$ for right-hand responses.

To corroborate this result, regressions for each individual separately were then run with RT as the outcome variable and response hand, size rating, and their interaction as the predictors Interaction coefficient values from these regressions for each participant were entered in an SPSS data file. A one sample $t$-test was then run on these interaction coefficient values to determine whether their mean of 0.91 differed from 0. It did not ($t[113] = 0.90, p < .365, d = .09, BF_{01} = 6.46$).

**Discussion**

Once again, no evidence for the presence of a SNARC-like effect was found in the responding to a living-nonliving judgment task involving a large number of singly presented names of things that differed widely in size. Although there was overall tendency for RT to decrease with size for this task (i.e., all of the slopes for both hands in either mapping order were negative), this tendency was not greater for right responses than left responses.

**General Discussion**

In the present experiments, participants judged both the sizes and the living-nonliving status of 400 animals, objects, etc. in order to determine whether a SNARC-like effect could be found in the responding to such judgments. Given that the stimuli were single, unrepeated instances from a large magnitude continuum, they were unlikely to be represented as an ordered array in either long-term memory (as would be numbers, months, and the alphabet) or short-term memory (as would be any finite, repeated set of items used in such an experiment). Hence, the presence of a SNARC-like effect here (i.e., a relation between relative size and the left-right response keys) would have provided evidence for a generalized association between space and magnitude information that does not depend on either canonical orderings in long-term memory or WM.

However, in the current study no evidence for a SNARC-like effect was found. In the first experiment, the interaction coefficient which indexes the difference in slope value for right-hand responses in comparison to the left-hand responses of participants, was indeed negative. Although this did suggest the presence of a trend towards declining RTs with size more for right-hand than for left-hand responses, it was not found
to be significant (and only occurred in the small-left and large-right first mapping order). In the second experiment, this same interaction coefficient was positive, small, and not significant.

As such, the current results conflict with those of Ren et al. (2011) and Sellaro et al. (2015) both of whom demonstrated SNARC-like effects for judgments involving analogous non-numerical stimuli. Hence, they represent an important non-replication of those earlier findings which have had key theoretical implications for the representation of quantity in the brain (c.f., Prpic et al., 2021). In this vein, although the current findings essentially represent null results, their place is not in the “file drawer”. Note that the main difference between the current paradigm and those of Ren et al. (2011) and Sellaro et al. (2015) is the use here of stimulus sampling from a potentially infinite set rather than from a finite fixed set. As discussed previously, stimuli taken from a fixed set are much more amenable to being represented in WM (and, hence, positionally) than are stimuli like the ones being used in this current work. One issue, though, is that the stimulus set used by Sellaro et al. (2015) did consist of 48 items in total (24 animals and 24 objects) which prompted Prpic et al. (2021) to remark that “it is hard to believe that the entire set of stimuli can be organized in an ordinal manner in working memory” (p. 2). One response to that point would be that the presence of SNARC-like effects necessarily implies that some kind of full or partial temporary position-based memory structure of the ordinal relations between the repeated stimuli in Sellaro et al. (2019) must have occurred because under conditions in which this is not possible, as in the current experiments, no SNARC-like effects are found.

Therefore, under conditions involving stimuli sampled individually without replacement from a large continuum of sizes in semantic memory, no spatial information seems to be accessed. Importantly, such conditions could actually be regarded as being prime for accessing such spatial information and, hence, observing SQUARC effects, according to the common magnitude representation view. In this vein, note that the current authors are actually quite sympathetic to such a view and fully expected to observe SNARC-like effects in the current work – which did not happen. Nonetheless, the lack of such effects here does not in any way serve to rule out the common magnitude representation view (for some intriguing recent work supporting it see Harvey et al., 2015), although it does serve to question the extent to which the representation of size and space might overlap. As well, the current results do not address the issue of whether the representations of other non-numerical magnitude domains, such as time, overlap with spatial representations (Macnamara et al., 2018).

Moreover, the present work could be regarded as representing a failed attempt to falsify the pure working memory account for spatial-numerical associations developed by Abrahamse et al. (2016). According to those authors, it represents a more parsimonious account for the results of the work reviewed earlier demonstrating the simultaneous presence of SNARC and ordinal position effects than one which assumes dual processes “in which spatial codes both derive directly from long-term memory and are formed at the level of working memory” (p. 4). According to the working memory account, spatial codes are not intrinsic to the representation of number in long-term memory (which is the core of the classic mental number line account for the SNARC effect) but “derive from task-specific and temporary binding of number items to a spatial template” (p. 4). Note that such a view does not eschew the notion that such
magnitudes can be represented in an ordered fashion in long-term semantic memory but only that a spatial component to such representations need not be assumed.

Finally, it must be noted that the current findings actually converge quite nicely with those reported in some very recent work by Cleland et al. (2020). Those researchers showed that when judging whether a set of triangles was pointed up or down by providing left-right manual responses, manipulation of the number of triangles in the display did not lead to the occurrence of SNARC-like effects. Importantly, the key aspect of their design was the use of multiple displays for each numerosity as opposed to a fixed repeated set with only one display for each increasing number of triangles. Those authors concluded that the lack of SNARC effects in their results could be regarded as being “consistent with such working memory accounts under the assumption that non-symbolic, non-canonical representations of number are more difficult to conceptualize as an ordered sequence” (p. 305).

In conclusion, the SNARC-like effects that were observed when judging non-numerical magnitudes in previous studies with finite repeated stimulus sets was not replicated here. Thus, the present study serves to provide boundary conditions on when researchers can expect to obtain such SNARC-like effects. Namely, when positional coding of such magnitude information is precluded, no such effect should occur.

**Declarations**

**Ethical Approval**

Ethics Approval for this study has been provided by the Carleton University Psychology Research Ethics Board.

**Competing interests**

None of the authors have any personal or financial conflict of interest regarding the work reported in this study.

**Authors’ contributions**

C. L., S.M.M.M.F., N. A. Conceptualization

C.L., N. A. - Data curation

C.L., S.M.M.M.F., N. A. - Formal analysis:

C.L., S.M.M.M.F., N. A. - Methodology

N. A.- Writing: original draft

C.L., S.M.M.M.F. - Writing: review & editing
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Availability of data and materials

All of the data and syntax for the analyses performed in this article submission can be found at https://osf.io/7pkst/?view_only=14cf067b0ff34534bdffab3dd4d14cf5).

References


**Footnotes**

1. Note that this analysis was rerun (i) as a simple comparison of all spatially congruent trials together versus all spatially incongruent trials, (ii) with only those who self-reported as being a native English speaker included, (iii) with all items removed that either had low accuracy (< 70%) or were regression outliers for a regression of mean item RTs on the, size, and their interaction, (iv) with random intercepts for the items specified in the linear mixed model, (v) separately for the set of fastest and slowest RTs for each participant, and (vi) with accuracy as the dependent variable. In all cases, no SNARC-related effect was significant.

2. Note that, again, this analysis was rerun (i) as a simple comparison of all spatially congruent trials together versus all spatially incongruent trials, (ii) with only those who self-reported as being a native English speaker included, (iii) with all items removed that either had low accuracy (< 80%) or were regression outliers for a regression of mean item RTs on the, size, and their interaction, (iv) with random intercepts for the items specified in the linear mixed model, (v) separately for the set of fastest and slowest RTs for each participant, and (vi) with accuracy as the dependent variable. In all cases, no SNARC-related effect was significant.
Figure 1

Relations between the size values of the animals/objects etc. and the mean response time (RT) aggregated over participants in Experiment 1. Separate scatterplots are shown for responses with the left and right hands.
Figure 2

Relations between the size values of the animals/objects etc. and the mean response time (RT) aggregated over participants in Experiment 2. Separate scatterplots are shown for responses with the left and right hands.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.
• Appendix.docx