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RESEARCH ARTICLE

Evidence of SQUARC and distance effects in a weight comparison task

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Abstract

Stimuli associated with large quantities are typically responded to faster with a right- than a left-side key, whereas stimuli associated with small quantities are typically responded to faster with a left- than a right-side key. This phenomenon is known as the *spatial-quantity association of response codes* (SQUARC) effect. Here, in two experiments, we explored whether a SQUARC effect can emerge for light versus heavy items. Participants judged whether the weight associated with a central target word, describing an animal (e.g. 'cow'; Experiment 1) or a material (e.g. 'iron'; Experiment 2), was lighter or heavier than the weight associated with a reference word. Responses were provided with a left- and a right-side button. Then, participants estimated the weight associated with target and reference words. In both experiments, evidence for a SQUARC effect emerged. Moreover, response times for each target word decreased with absolute difference between its rated weight and the rated weight of the reference word, in line with a distance effect. Overall, these results provide evidence of a possible spatial representation of weight.

Keywords SQUARC effect · SNARC-like effect · Distance effect · Spatial coding · Weight judgment

Introduction

Early evidence that magnitudes can arrange along a hypothetical mental line can be found in the seminal work by Moyer and Landauer (1967) on the *distance effect*: In that study, when participants were asked to decide which number in a pair was the largest, reaction times (RTs) tended to decrease with absolute difference between the numbers. A possible interpretation of this effect is that the farther apart two numbers are on the mental number line, the easier it is to decide which is the largest and therefore the shorter the RTs (see also Dehaene et al. 1990; Krause et al. 2013; Treccani and Umiltà 2011; cf. Fischer and Shaki 2011; Herrera et al. 2008). More recent evidence suggests that this mental number line could also be oriented in space, with smaller quantities represented on the left and larger quantities represented on the right (Dehaene 1997; Dehaene et al. 1993). For instance, in the study by Dehaene et al. (1993), participants pressed a left- or a right-side key to classify a centrally placed number as either even or odd. The main finding was that faster responses were recorded when the mapping between the numbers and response key was compatible with a left-to-right spatial representation of numbers (i.e. smaller-left; greater-right) rather than incompatible (i.e. smaller-right; greater-left), a phenomenon known as the *spatial-numerical association of response codes* (SNARC) effect.

The SNARC effect has been widely replicated and explored (for a meta-analysis and review, see Wood et al. 2008), and it appears to be largely independent of both the format of number stimuli (e.g. Arabic digits versus number words; see Nuerk et al. 2005) and the effectors used to provide the response (e.g. hands versus feet; see Schwarz and Müller 2006). Nevertheless, the interpretation of the SNARC effect is still widely debated. For instance, no consensus has yet been reached on whether the association between space and numbers is intrinsic and mandatory, or whether it stems from flexible, task-dependent strategies (e.g. Fischer 2006; Fischer and Shaki 2011; van Dijck and Fias 2011). In support to the latter hypothesis, it has been shown that the SNARC effect can be shaped by cultural background (e.g. reading/writing habits; see Dehaene et al. 1993; Fischer et al. 2009; Shaki et al. 2009) and by stimulus-specific

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associations between numbers and space (Fischer et al. 2010). Interestingly, SNARC-like effects have also been reported in response to alphabet letters and months (Gevers et al. 2003) suggesting that—at least in some cases—the spatially oriented stimuli representation may be based on a given order along a sequence rather than on magnitude per se. Recently, the possible nature of the SNARC effect has been discussed within a novel theoretical framework known as the Tropic, Embodied, and Situated Theory of Cognition (TEST; Myachykov et al. 2014), which provides an intriguing explanation on how spatial representations (including the representation of numbers) would be generated. According to TEST theory, spatial representations are hierarchically organised. The most stable, generic, and automatic component of this hierarchy is the *tropic* representation—related to constraints of the physical world (e.g. 'up' is often associated with 'more'). Then, there is the *embodied* representation, related to the bodily constraints of an individual's aims (e.g. finger-counting habits), which is less stable as compared to the tropic representation. Finally, there is the *situated* representation, which is dynamic and unstable and related to task-specific requirements and individual's aims (e.g. responses are provided with left- and right-side keys). The TEST theory provides a useful perspective to interpret how different experimental conditions—calling into question tropic, embodied, or situated representations—would be able to elicit a SNARC effect. Another possible interpretation of the SNARC effect has been provided by the so-called polarity correspondence model (Proctor and Cho 2006). According to this model, when participants are required to classify stimuli magnitude by providing lateralised responses, both stimuli and responses would be implicitly coded, with large magnitudes and right-side responses being coded as positive polarities and small magnitudes and left-side responses being coded as negative polarities. Consequently, responses would be faster for identical (i.e. small-left; large-right) than different (i.e. small-right; large-left) polarities.

Interestingly, some authors pushed forward the idea that the SNARC effect could be the manifestation of a more general mechanism devoted to the processing of magnitudes (see Cohen Kadosh et al. 2008; Walsh 2003, 2015). In particular, the SNARC effect would be a specific case of a *spatial-quantity association of response codes* (SQUARC) effect. In this regard, evidence for a SQUARC effect emerged for non-numerical dimensions like loudness (Bruzzi et al. 2017; Chang and Cho 2015; Hartmann and Mast 2017), luminance (Fumarola et al. 2014; Ren et al. 2011) and time (Vallesi et al. 2008). For instance, in Chang and Cho (2015), participants decided whether the loudness of a target tone was either lower or higher as compared to a reference tone. The results showed that that RTs were faster when 'lower' response was associated with a left-side key and 'higher' response was associated with a right-side key, as compared to the reverse mapping (i.e. lower-right; higher-left). However, the difference between left- and right-side responses was larger for the higher tone than for the lower tone. Similarly, Vallesi et al. (2008) asked participants to decide whether a centrally placed fixation cross was presented for either a short (i.e. 1 s) or a long (i.e. 3 s) temporal duration. The results showed that RTs were faster when 'short' response was associated with a left-side key and 'long' response was associated with a right-side key, as compared to the reverse mapping (i.e. short-right; long-left).

More related to the present work, another non-numerical dimension that can elicit a SQUARC effect is object size (Ren et al. 2011; Sellaro et al. 2015; see also Shaki et al. 2012). In this regard, Ren et al. (2011) asked participants to decide whether a centrally placed target shape was either smaller or larger as compared to a reference shape (Experiment 2) or whether a centrally placed target word referred to an object that was either smaller or larger as compared to an object described by a reference word (Experiment 4). In both experiments, right-side responses were faster to larger items as compared to smaller items, while no significant differences between smaller and larger items emerged for left-side responses. In a similar vein, Sellaro et al. (2015) presented participants with a centrally placed target word referring to either an animal or to an inanimate object. The task was to judge whether the size associated with the target word was either smaller or larger as compared to a reference word. Here, shorter RTs were recorded when 'smaller' response was associated with a left key and 'larger' response was associated with a right key, as compared to the reverse mapping (i.e. smaller-right; larger-left). Overall, the SQUARC effects emerging from these size comparison tasks may suggest that small items are represented on the left, and large items are represented on the right. Finally, size dimension was manipulated also in the study by Shaki et al. (2012, Experiment 1), in which participants were instructed to press a left- or a right-side button to indicate either the smaller or the larger animal described in a pair of two words. These pairs referred to either relatively small (e.g. snail and mouse) or large (e.g. whale and moose) animals. Interestingly, when participants had to choose the smaller animal, left-side responses were faster for relatively small pair of words, whereas right-side responses were faster for relatively large pair of words. On the contrary, when the larger animal had to be chosen, the association between small–large and left–right tended to be inverted. This highlights that, when stimuli are presented in pairs, the SQUARC effect for size may also depend on the type of instruction given to participants (i.e. 'choose the smaller' vs. 'choose the larger' animal).

In addition to size, another property of objects which is relevant both at a physical and at a perceptual level is weight. Even though weight can strongly shape the way we interact with the physical world around us, knowledge concerning how weight is treated and represented within our cognitive system is still limited, and mostly confined to the influence of top-down expectations on perceived weight (e.g. Buckingham 2014; Dijker 2014; Flanagan et al. 2008; Ross 1969). For instance, a well-known phenomenon concerning weight perception is the material-weight illusion: When two objects of the same physical weight but different surface materials are lifted, the object that appears to be made of the less dense material, like plastic, usually feels heavier than the object that appears to be made of the denser material, like steel (see Buckingham et al. 2011; Ellis and Lederman 1999; see also Buckingham and MacDonald 2016; Vicovaro and Burigana 2017). To the best of our knowledge, so far, no studies have directly explored the possibility of observing a SQUARC effect for weight dimension. In line with the assumption of a general mechanism devoted to magnitude processing (see Cohen Kadosh et al. 2008; Walsh 2003, 2015), it is reasonable to expect that our cognitive system may represent weight magnitudes in a spatially coded manner, as reported for other non-numerical dimensions (e.g. luminance, time, or size). Recently, in Holmes and Lourenco (2013), participants completed a standard SNARC task (e.g. Dehaene et al. 1993), while wearing a weight on either the left or the right wrist (i.e. left and right condition, respectively). In a baseline condition, no weight was employed. Interestingly, the SNARC effect emerged in both the baseline and the right conditions, but not in the left condition. According to the authors, the left condition elicited a right-to-left representation of quantity, which counteracted the left-to-right representation of numbers, thus nullifying the SNARC effect. Overall, this result suggests the presence of a potential link between weight and the spatial representation of numbers.

Here, two experiments were carried out to directly test whether a SQUARC effect may emerge in a weight comparison task. Experiment 1 was inspired by Sellaro et al. (2015), who found a SQUARC effect elicited by the size associated with different target words describing animals. In the present context, we employed the same target words of Sellaro et al. (2015) with the aim of showing that these stimuli can also elicit a SQUARC effect based on weight. More precisely, participants were asked to decide, in a comparison task, whether a centrally placed target word described an animal that was either lighter or heavier—rather than smaller or larger, like in the study by Sellaro et al. (2015)—than a reference animal. Responses were provided by pressing a left-side and a right-side key. The same task was also employed in Experiment 2, but words described materials (e.g. iron) which—contrarily to animals—are not necessarily associated with a prototypical size. In so doing, we aimed to reduce the potential impact of size on the SQUARC effect. Indeed, in the natural world, size and weight can be strongly intertwined (e.g. larger animals are also heavier than smaller animals). For this reason, Experiment 2 was an attempt to dissociate weight from size, a potential confound that was likely present in previous studies exploring the SQUARC effect for size (Ren et al. 2011; Sellaro et al. 2015; Shaki et al. 2012). In both experiments, we expected to observe shorter RTs when lighter stimuli were associated with the left-side response and heavier stimuli were associated with the right-side response, as compared to the reverse mapping (i.e. lighter-right, heavier-left). This pattern of results would provide supporting evidence of a SQUARC effect for weight. Further support for a possible relationship between weight magnitudes and space could also be provided by a distance effect. For this reason, after performing the comparison task, participants were also asked to rate the weight implied by both the reference and the target words. We expected that the greater the absolute difference between the rated weight of the target and the reference word, the shorter the RTs recorded in the comparison task.

Experiment 1

Materials and methods

Participants

Twenty-six students naïve as to the objective of the study (*Mean age* = 23 years, *SD* = 2.14, 10 males) were tested. The number of participants is coherent with the guidelines proposed by Brysbaert and Stevens (2018) for linear mixed-effect models with subjects and items as random factors (see the result section). According to these guidelines, at least 1600 observations per condition should be collected. This warrants adequate statistical power in the case of the small effect sizes that generally characterise RT studies. Here, since we planned to collect 84 trials per condition for each participant, a minimum number of 20 participants were required. Informed consent was obtained from all individual participants included in the study. All participants declared to be right-handed. Manual preference was further assessed through the Edinburgh Handedness Inventory (EHI; Oldfield 1971), which provides a continuous handedness score on a scale ranging from − 100 (i.e. strong preference for the left hand) to 100 (i.e. strong preference for the right hand). Here, the mean EHI score was 70 (range: from 40 to 100).

Stimuli, apparatus and procedure

The reference word used was ‘sheep’. Twenty-four target words were used, half describing an animal lighter than a sheep, and half describing an animal heavier than a sheep.

Table 1 Stimuli used in the two experiments. Italian words are in parentheses. In both experiments, lighter and heavier word stimuli did not differ neither for word length ($ps > .72$) nor for log-transformed word frequency expressed as instances per million words ($ps > .41$; itWac corpus; Baroni et al. 2009)

	Reference word	Target words	
		Lighter weight	Heavier weight
Experiment 1	Sheep (*Pecora*)	1. Ant (*Formica*)	13. Cow (*Mucca*)
		2. Bee (*Ape*)	14. Deer (*Cervo*)
		3. Beetle (*Scarafaggio*)	15. Bear (*Orso*)
		4. Caterpillar (*Bruco*)	16. Elephant (*Elefante*)
		5. Crab (*Granchio*)	17. Giraffe (*Giraffa*)
		6. Fly (*Mosca*)	18. Gorilla (*Gorilla*)
		7. Grasshop (*Cavalletta*)	19. Hippo (*Ippopotamo*)
		8. Ladybug (*Coccinella*)	20. Horse (*Cavallo*)
		9. Lizard (*Lucertola*)	21. Rhino (*Rinoceronte*)
		10. Mouse (*Topo*)	22. Walrus (*Tricheco*)
		11. Scorpion (*Scorpione*)	23. Whale (*Balena*)
		12. Snail (*Lumaca*)	24. Zebra (*Zebra*)
Experiment 2	Wood (*Legno*)	1. Cloth (*Stoffa*)	6. Cement (*Cemento*)
		2. Plastic (*Plastica*)	7. Iron (*Ferro*)
		3. Paper (*Carta*)	8. Lead (*Piombo*)
		4. Sponge (*Spugna*)	9. Marble (*Marmo*)
		5. Rubber (*Gomma*)	10. Steel (*Acciaio*)

The word stimuli were presented in Italian (see Table 1; see also Sellaro et al. 2015).

Stimuli were presented using E-Prime 2 (Psychology Software Tools, Pittsburgh, PA) on a PC monitor (1280×1024 px; 60 Hz), placed at 57 cm from the participant. The background was set to grey. Manual responses were collected through a standard keyboard, which has appropriate accuracy for RT recordings (see E-Prime guidelines). The keyboard was placed in between the participant and the monitor. Moreover, the keyboard was placed in order to keep the two response keys (A and K) equally distant from the centre of the screen.

For the comparison task, each trial started with a black central fixation cross (24-point Courier New font; see Fig. 1, panel A). After 700 ms, the cross was replaced by a randomly selected black target word (24-point Courier New font) and participants were asked to decide, as quickly and accurately as possible, whether the animal described by the target word was either 'lighter' or 'heavier' than the animal described by the reference word (sheep).[1] Responses were provided by pressing the A key with the left index finger and the K key with the right index finger. After either a response or a 1500-ms timeout limit (whichever came first), a central black letter (24-point Courier New font) was provided as feedback for 500 ms (i.e. a central 'O' for correct responses; a central '*X*' combined with an acoustic buzz for both wrong and missed responses). Finally, a blank screen appeared for 800 ms. There were two experimental blocks, each composed of 168 trials (i.e. 336 experimental trials in total) and

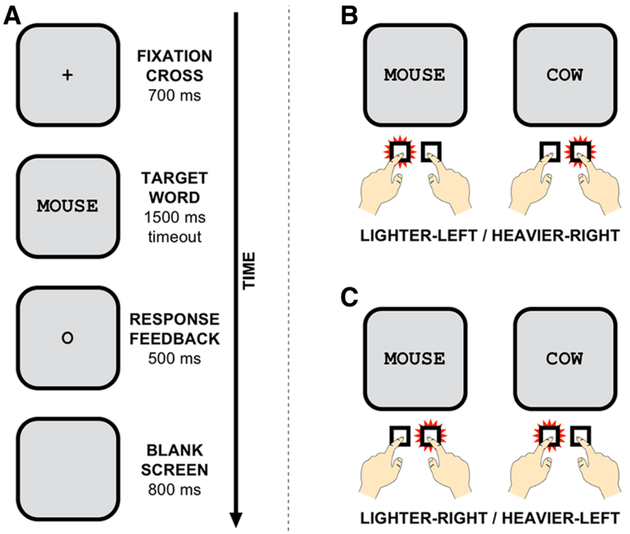

Fig. 1 Panel A depicts an example of a trial. Panel B shows examples of the lighter-left/heavier-right mapping, in which the target word 'mouse' is correctly responded with the left-side key and the target word 'cow' is correctly responded with the right-side key. Panel C shows examples of the reverse mapping (i.e. lighter-right/heavier-left), in which the target word 'mouse' is correctly responded with the right-side key and the target word 'cow' is correctly responded with the left-side key

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[1] Even if in English the word 'light' may refer not just to lightness in weight, but also to lightness in colour, in Italian there is no obvious confounding for words related to weight and words related to other physical dimensions. For instance, there is no confounding between the Italian words '*leggero*' (light in weight) and '*chiaro*' (light in colour).

preceded by a practice block of 24 trials. Each target word was presented randomly and for an equal number of times, in both the experimental (i.e. 7 times per block) and the practice (i.e. 1 time per block) sessions. The association between response sides and ‘lighter’ and ‘heavier’ responses was inverted in the two blocks, namely in one block ‘lighter’ was associated with the left-side response and ‘heavier’ with the right-side response (Fig. 1, panel B), whereas in the other block the opposite was true (Fig. 1, panel C). Block order was counterbalanced across participants.

The comparison task was followed by a rating task, in which participants estimated the weight associated with the word stimuli on a 1- to 100-point scale. In this scale, ‘1’ and ‘100’ corresponded to the weight of an ant (i.e. the lower anchor) and a whale (i.e. the upper anchor), respectively. On each trial, a black word stimulus (24-point Courier New font) was presented at the centre of the screen with no time limits. Participants reported the weight associated with the animal by typing the value on the keyboard. Then, the response was confirmed by pressing the enter key. There was an experimental block, in which each word was presented three times, preceded by a practice block, in which three words were presented.

At the end of the rating task, participants completed the EHI.

Results and discussion

In the comparison task, missed responses (0.14% of trials) and wrong responses (2.21% of trials) were deleted and excluded from further analyses. Outliers, defined as correct trials with RTs three standard deviations (SD) above or below the participant’s mean, were also removed (1.93% of trials). In so doing, each condition was associated with a minimum number of 2070 observations, thus warranting adequate statistical power (see Brysbaert and Stevens 2018).

In accordance with the guidelines proposed by Baayen et al. (2008) for experiments employing linguistic stimuli, we analysed RTs of correct trials using a linear, mixed-effects model (R package *lme4*; Bates et al. 2015). Similarly to previous studies on SQUARC effects that employed a standard ANOVA approach (e.g. Chang and Cho 2015; Ren et al. 2011; Vallesi et al. 2008), we entered, as fixed effects, the relative weight associated with the target word (lighter vs. heavier than the reference word ‘sheep’), response side (left vs. right), and the interaction term.[2] For random effects, we had intercepts for subjects and items (i.e. target words), as well as by-subject random slopes for the effects of weight and response side. This model was the one that best fitted the data according to a likelihood ratio test comparing increasingly complex models (from the null to the saturated model). The model was then entered into a Type 1 ANOVA (Satterthwaite’s approximation for degrees of freedom) for linear mixed-effects models (R package *lmerTest*; Kuznetsova et al. 2017). Evidence of a SQUARC effect would be provided by a significant two-way interaction between relative weight and response side (i.e. for ‘heavier’ target words, shorter RTs for right- than for left-side responses, and the opposite for ‘lighter’ target words). Effect sizes were calculated according to the formulas provided by Westfall et al. (2014; see also Brysbaert and Stevens 2018) for linear mixed-effect models. The results showed that the main effect of weight was not statistically significant, $F(1, 30.0) = 0.79$, $p = .38$, $d = 0.03$, whereas the main effect of response side was statistically significant, $F(1, 25.1) = 5.09$, $p = .033$, $d = 0.04$, showing that right-side responses were reliably faster ($M = 593$ ms, SE = 10.16) than left-side responses ($M = 601$ ms, SE = 10.48). The interaction between the two factors was significant, $F(1, 8284.3) = 15.65$, $p < .001$, $d = 0.04$. Planned Tukey’s HSD comparisons for linear mixed-effects models (R package *lsmeans*; Lenth 2016) showed that while no significant differences between left-side responses ($M = 593$ ms, SE = 10.5) and right-side responses ($M = 594$ ms, SE = 10.37) emerged for ‘lighter’ target words, $t(46.37) = -0.1$, $p = .92$, $d = -0.04$, ‘heavier’ target words led to shorter RTs for right-side responses ($M = 593$ ms, SE = 11.65) than for left-side responses ($M = 609$ ms, SE = 12.09), $t(46.87) = -3.98$, $p < .001$, $d = -1.62$ (Fig. 2). Overall, this pattern of results provides supporting evidence of a SQUARC effect for weight. Notably, a difference in RTs between left- and right-side responses emerged for ‘heavier’ but not for ‘lighter’ target words, which is consistent with some previous studies (e.g. Chang and Cho 2015; di Rosa et al. 2017). Arguably, this result emerged because right-side responses were overall faster than left-side responses, likely reflecting that all participants were right-handed (i.e. a handedness effect). Hence, the advantage for right-side responses might have masked the tendency to respond faster with the left key when a ‘lighter’ word was presented. Nevertheless, the significant two-way interaction between relative weight and response side indicates the presence of a SQUARC effect.

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[2] The SNARC effect is frequently tested by computing, for each number stimulus, the mean RT difference between the right- and the left-side key, and then by testing the existence of a negative correlation between number magnitudes and mean RT difference (see Fias et al. 1996). Theoretically, this approach could also be used in the current context by using the mean rated weight of the stimuli instead of number magnitude. However, when magnitude is task relevant as in our study (see the general discussion), the mean RT difference is not a linear but a categorical function of magnitude, which implies the violation of one basic assumptions of linear regression analysis (see Gevers et al. 2006).

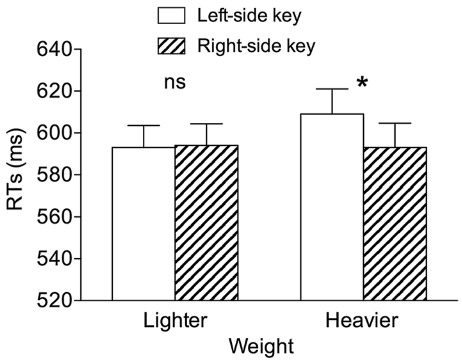

Fig. 2 Mean RTs observed in the comparison task of Experiment 1. *=p < .05; *ns* = non-significant. Error bars are standard errors of the mean

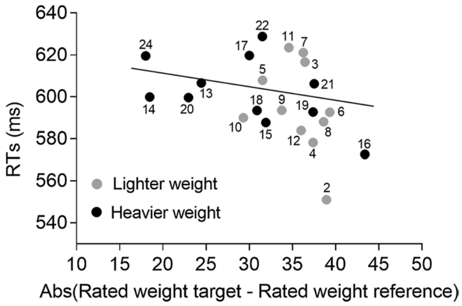

Fig. 3 Mean RTs for each target word (excluding the two anchors, 'ant' and 'whale') as a function of the mean absolute difference between its rated weight and the rated weight of the reference (i.e. 'sheep'). Black and grey circles are for 'heavier' and 'lighter' target words, respectively. Numbers refer to the word list reported in Table 1 (Experiment 1). The intercept and slope of the regression line are 627.8 ms and − 0.875, respectively

In order to test for the existence of a distance effect, we first computed, for each participant, the mean RTs associated with each target word. Then, we computed the absolute difference between the mean rated weight of each target word and the mean rated weight of the reference word. The distance effect implies shorter RTs for larger absolute differences between the weight associated with the target word and the weight associated with the reference word. This negative relationship was indeed confirmed by a linear mixed-effects regression analysis with fixed effects for the intercept and the slope of the regression line relating RTs to rating differences, and random (by-subject) effects for the intercept and the slope of the same regression line, $b = -0.88$, $SE_b = 0.19$, $t(24.29) = -4.52$, $p < .001$ (see Fig. 3). Moreover, the mean absolute difference between the weight of 'heavier' words and the weight of the reference ($M = 29.69$, SE = 0.95), was smaller than that between the weight of 'lighter' words and the weight of the reference ($M = 35.66$, SE = 2.44, $t(12.96) = -2.28$, $p < .05$, $d = -0.97$). Namely, 'heavier' words were represented as closer to the reference than 'lighter' words (see also Fig. 3). It is also worth noting that left-side responses for 'heavier' words tended to be slower than the responses in the other conditions (see Fig. 2). We can hypothesise that this finding was due to the combination of the SQUARC effect (for 'heavier' words, left-side responses were slower than right-side responses), the handedness effect (left-side responses were slower than right-side responses) and the distance effect (responses to 'heavier' words were slower than responses to 'lighter' words).

Finally, we also explored whether the degree of handedness (i.e. EHI scores) predicted the SQUARC effect magnitude (computed as reported in the "Appendix"), in line with the *body-specificity hypothesis* (Casasanto 2009). Indeed, Casasanto (2009) showed that right-handers represented negative concepts (e.g. 'bad) on the left, and positive concepts (e.g. 'good) on the right, whereas the reverse mapping emerged for left-handers. Here, a positive correlation between the EHI scores and the SQUARC effect magnitude would be indicative of a positive relationship between the degree of right-hand preference and the strength of the left-to-right representation of weight. However, a non-significant negative correlation emerged ($b = -0.55$, $SE_b = 0.68$, $t(24) = -0.81$, $p = .42$, $r^2 = 0.027$; see also Fig. 6).

Experiment 2

Experiment 1 provided evidence that target words referring to animals can elicit a SQUARC effect based on weight, thus extending Sellaro et al. (2015) who reported—for the same target words—a SQUARC effect based on size. In Experiment 2, we aimed to replicate the results of Experiment 1 by using word stimuli referring to materials (e.g. iron) instead of animals. We decided to use materials mainly because, differently from animals, they are not necessarily associated with a given size. For instance, plastic can be used to create objects of different dimensions, such as a shirt button or a table. Moreover, the material-weight illusion provides indirect evidence that, regardless of size, denser materials (e.g. metals) are expected as heavier than less dense materials (e.g. wood or polystyrene; see Buckingham et al. 2011; Vicovaro and Burigana 2017). For these reasons, materials appear to be suitable to get a reliable manipulation of weight. Hence, we sought to obtain further supporting evidence for the hypothesis that weight can elicit both a SQUARC and a distance effect—even when weight is not strictly coupled with size.

Materials and methods

Participants

A new sample of 26 students naïve as to the objective of the study (*Mean age* = 19 years, *SD* = 0.86, 7 males) were tested. Since we planned to collect 75 trials per condition for each participant, a minimum number of 22 participants was required (see Brysbaert and Stevens 2018). Informed consent was obtained from all individual participants included in the study. Three participants declared to be left-handers. However, one of these three participants had an EHI of 50, which suggests a preference for the right hand. Overall, the EHI provided a mean score of 57 (range: from -55 to 100).

Stimuli, apparatus and procedure

Everything was identical to Experiment 1, with the following exceptions: The reference word was ‘wood’ and 10 target words were used, half describing a material lighter than wood, and half a material heavier than wood (see Table 1). Moreover, the two experimental blocks were composed of 150 trials each (i.e. 300 experimental trials in total) and were preceded by a practice block of 20 trials. Each target word was presented randomly and for an equal number of times, in both the experimental (i.e. 15 times per block) and the practice (i.e. 2 times per block) sessions. Finally, in the rating task, the lower and the upper anchors were ‘feather’ and ‘truck’, respectively, and all the target words were presented.[3]

Results and discussion

Data were analysed as in Experiment 1.

For the comparison task, missed responses (0.18% of trials), wrong responses (2.58% of trials) and outliers (1.74% of trials) were removed and excluded from further analyses. In so doing, each experimental condition was associated with a minimum number of 1852 observations, thus warranting adequate statistical power (see Brysbaert and Stevens 2018).

The model that best fitted RTs of correct trials according to a likelihood ratio test comparing increasingly complex models (from the null to the saturated model) included, as fixed effects, the relative weight implied by the target word (lighter vs. heavier than the reference word ‘wood’), response side (left vs. right), and the interaction term. As random effects, it included intercepts for subjects and items (i.e. target words), by-subject random slopes for the effects of weight and response side, and by-item random slopes for the effects of response side. The results showed that the main effect of weight was not statistically significant, $F(1,\ 8.64) = 2.90$, $p = .12$, $d = 0.05$, as well as the main effect of response side, $F(1,\ 14.23) = 4.22$, $p = .059$, $d = 0.03$. Although the latter main effect fell short of statistical significance, right-side responses ($M = 554$ ms, SE = 12.53) tended to be faster than left-side responses ($M = 562$ ms, SE = 13.12). The interaction between the two factors was significant, $F(1,\ 7.98) = 14.71$, $p < .01$, $d = 0.05$. Planned Tukey’s HSD comparisons showed that while no significant differences between left-side responses ($M = 562$ ms, SE = 13.66) and right-side responses ($M = 565$ ms, SE = 13.16) emerged for ‘lighter’ target words, $t(12.30) = -0.77$, $p = .45$, $d = -0.49$, ‘heavier’ target words led to shorter RTs for right-side responses ($M = 542$ ms, SE = 12.96) than for left-side responses ($M = 561$ ms, SE = 13.68), $t(12.14) = -3.98$, $p < .005$, $d = -2.52$ (Fig. 4). As in Experiment 1, the significant two-way interaction between relative weight and response side indicates the presence of a SQUARC effect. As in Experiment 1, a difference in RTs between left- and right-side responses emerged for ‘heavier’ but not for ‘lighter’ target, likely because most of the participants were right-handed.

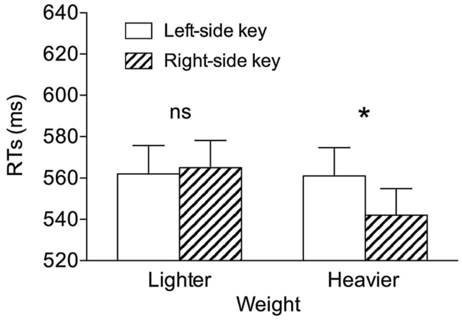

Fig. 4 Mean RTs observed in the comparison task of Experiment 2. $* = p < .05$; *ns* = non-significant. Error bars are standard errors of the mean

As for the distance effect, a linear mixed-effects regression analysis was performed, with fixed effects for the intercept and the slope of the regression line relating RTs to rating differences, and random (by-subject) effects for the intercept of the same regression line. The analysis revealed a statistically significant negative relationship between mean RTs and the absolute difference between the mean weights of the target and the reference word, $b = -0.37$, $\mathrm{SE}_b = 0.09$, $t(234.08) = -4.28$, $p < .001$ (see Fig. 5). Moreover, the mean absolute difference between the weight of ‘heavier’ words and the weight of the reference ($M = 36.5$, SE = 2.8), was larger than that between the weight of ‘lighter’ words and the weight of the reference ($M = 18.14$, SE = 1.66, $t(6.5) = 5.63$, $p < .005$, $d = 3.99$). Namely, ‘heavier’ words were represented farther from the reference than ‘lighter’ words (see also Fig. 5). This pattern was the opposite of what we observed in Experiment 1. We also note that, differently

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[3] Please note that anchors and target words belonged to different categories (i.e. objects vs. materials, respectively). For the sake of reliability of the rating scale, the weight implied by the two anchors should be represented similarly among participants, and we reasoned that this was more easily achieved by using familiar objects instead of materials.

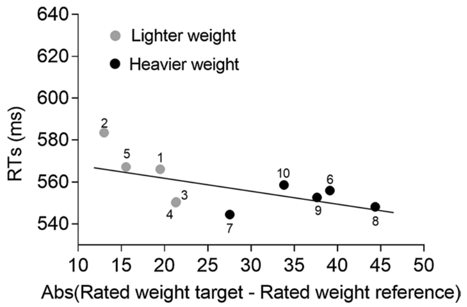

Fig. 5 Mean RTs for each target word as a function of the mean absolute difference between its rated weight and the rated weight of the reference (i.e. 'wood'). Black and grey circles are for 'heavier' and 'lighter' target words, respectively. Numbers refer to the word list reported in Table 1 (Experiment 2). The intercept and slope of the regression line are 567.98 ms and -0.373, respectively

from Experiment 1, right-side responses for 'heavier' words tended to be faster than the responses in the other conditions (see Fig. 4). We can hypothesise that this finding was due to the combination of the SQUARC effect (for 'heavier' words, right-side responses were faster than left-side responses), the handedness effect (right-side responses tended to be faster than left-side responses) and the distance effect (responses to 'heavier' words were faster than responses to 'lighter' words).

Finally, as in Experiment 1, a linear regression analysis between the EHI scores and the SQUARC effect magnitude (see the "Appendix") was performed. Similarly to Experiment 1, the results showed a non-significant negative correlation ($b=-0.37$, $SE_b=0.38$, $t(24)=-0.96$, $p=.34$, $r^2=0.037$). This held true even when the data of the two experiments were combined ($b=-0.41$, $SE_b=0.31$, $t(50)=-1.32$, $p=.19$, $r^2=0.034$), confirming the lack of a linear relationship between the degree of right-hand preference and the strength of the left-to-right representation for weight (see Fig. 6).

Overall, the results of Experiment 2 align with those observed in Experiment 1, as we found evidence of both a SQUARC and a distance effect for weight.

General discussion

In two experiments we explored the possible existence of both SQUARC (e.g. Walsh 2003) and distance (e.g. Krause et al. 2013) effects in a weight comparison task. More precisely, participants were asked to press either a left- or a right-side response key to classify a centrally placed target word—describing an animal (e.g. cow; Experiment 1) or a material (e.g. iron; Experiment 2)—as either lighter or heavier than a reference word. We hypothesised that, in line with a SQUARC effect, responses would be faster when 'lighter' was associated with the left response side and 'heavier' was associated with the right response side, as compared with the reverse mapping (i.e. lighter-right; heavier-left). Overall, the results of both experiments provided support to this hypothesis, even if a difference between left- and right-side responses emerged only for 'heavier' words (for similar results, see also Chang and Cho 2015; di Rosa et al. 2017). After the comparison task, participants were asked to rate the weight associated with each word stimulus. A negative correlation emerged between the mean RTs for a given target word and the absolute difference between its mean rated weight and the mean rated weight of the reference word, thus indicating a distance effect. Taken together, these results are consistent with the hypothesis that 'lighter' items might be represented on the left, and 'heavier' items might be represented on the right. This is also consistent with some previous studies in which a SQUARC effect emerged even for non-numerical dimensions, such as loudness (e.g. Chang and Cho 2015), luminance (e.g. Fumarola et al. 2014), time (Vallesi et al. 2008) and size (e.g. Sellaro et al. 2015).

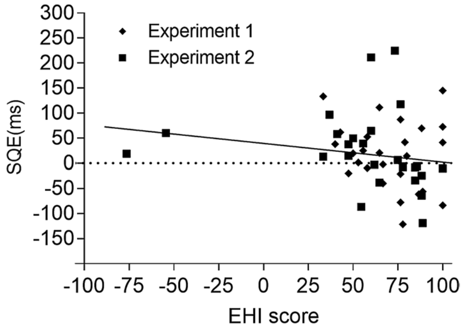

Fig. 6 SQEs for each participant as a function of EHI scores. The intercept and slope of the regression line are 46.3 ms and -0.41, respectively

It is important to remember that in the natural world weight is intertwined with size, since heavier objects are also typically larger than lighter objects. The positive relationship between weight and size was particularly evident for the set of word stimuli—taken from Sellaro et al. (2015)—employed in Experiment 1, namely animals. For instance, a mouse is not only lighter but also smaller than a sheep and, symmetrically, a cow is not only heavier but also larger than a sheep. The results of Experiment 1 suggest that these items can lead to a SQUARC effect based on weight, other than on size such as in the study by Sellaro et al. (2015). The weight–size correlation was less obvious for the set of word stimuli employed in Experiment 2, as materials are not necessarily associated with a given size. For instance, everyday life objects made of a light (i.e. low density) material, like plastic, can be either small (e.g. a shirt button) or large (e.g. a table). Likewise, objects made of a heavy (i.e. high density) material, like steel, can be either small (e.g. a fork) or large (e.g. a car). The SQUARC and distance effects, which emerged in both experiments, provide support for the hypothesis that a possible link between weight magnitudes and space may emerge both when weight and size are strictly related (i.e. Experiment 1) and when this relationship is weaker (i.e. Experiment 2). Nevertheless, we cannot unambiguously exclude the possibility that, in Experiment 2, light and heavy materials might have also activated an implicit representation of small- and large-size objects, respectively.

Notably, the standard SNARC effect introduced by Dehaene et al. (1993) has been widely explored by making numerical magnitude either task relevant or task irrelevant. On the one hand, when magnitude is task relevant, participants are typically asked to decide whether the target number is either smaller or larger than the reference number. On the other hand, when magnitude is task irrelevant, participants are typically asked to decide whether the target number is either even or odd. Similarly to the standard SNARC effect, SQUARC effects have also been explored by varying the relevance of target dimension. In some studies, target dimension was only task relevant (see Bruzzi et al. 2017; Ren et al. 2011; Vallesi et al. 2008). For instance, in five experiments Ren et al. (2011) asked participant to directly compare the magnitude of a target and a reference stimulus varying in numerical/physical size (smaller or larger; Experiments 1, 2, 4), luminance (lighter or darker; Experiment 3) and auditory intensity (quieter or louder; Experiment 5). In other studies, target dimension was both task relevant and irrelevant (see Chang and Cho 2015; Fumarola et al. 2014; Hartman and Mast 2017; Sellaro et al. 2015). For instance, in the study by Sellaro et al. (2015; Experiment 2), participants were asked to decide whether the centrally placed target word, referring to either an animal or to an inanimate object, was either smaller versus larger than a reference (i.e. size was task relevant) or 'animate' versus 'inanimate' (i.e. size was task irrelevant). When the target word referred to a small item, shorter RTs emerged when the correct response was associated with a left- than a right-side key, whereas when the target word referred to a large item, shorter RTs emerged when the correct response was associated with a right- than a left-side key. According to the authors, this could provide support for a SQUARC effect based on size. However, the strong correlation between size and weight as for the stimuli employed by Sellaro et al. (2015) invite caution. Indeed, our data suggest that these stimuli can also lead to a weight-based SQUARC effect, in line with the existence of a general mechanism for magnitude processing (e.g. Walsh 2003, 2015).

Taken together, our results are consistent with the hypothesis of an intrinsic spatially coded representation of weight (see also Walsh 2003). However, since the nature of SQUARC effects is still widely debated, alternative interpretations are worthy of consideration. For instance, according to the polarity correspondence model (see Proctor and Cho 2006), 'lighter' and 'left' could be associated with a negative polarity, whereas 'heavier' and 'right' could be associated with a positive polarity. Consequently, faster responses would emerge when there is a match between polarities (i.e. lighter-left; heavier-right) rather than a mismatch (i.e. heavier-left; lighter-right). Our data also fit with this prediction and can therefore be interpreted in terms of polarity correspondence. Additionally, we cannot exclude that the left-to-right mapping of weight might result from dynamic and unstable task-dependent strategies (e.g. Fischer 2006), in line with a *situated* representation of weight (see Myachykov et al. 2014). More precisely, since responses were provided with lateralised response keys, this may have prompted participants to spontaneously represent items along a left-to-right axis.

In future studies, it will be of great interest to investigate the SQUARC effect for weight by employing a vertically oriented response box, thus allowing for testing two competing hypotheses. On the one hand, the vertical representation of weight might be similar to that of other magnitudes—such as numbers (e.g. Winter et al. 2015; see also Shaki and Fischer 2018) or loudness (e.g. Bruzzi et al. 2017)—in which 'smaller' and 'larger' are typically associated with lower and upper keys, respectively (i.e. 'up' is typically associated with 'more'; see Myachykov et al. 2014). On the other hand, the vertical representation of weight might be linked to gravity force. In line with this notion, 'lighter' and 'heavier' responses should be faster if provided with the upper and the lower response key, respectively. Furthermore, the potential existence of body-specific representation of weight (see Casasanto 2009) should be further explored by testing a larger number of participants, equally divided in left- and right-handers.

To conclude, two experiments based on weight comparison tasks revealed distance and SQUARC effects for weight (we may call this a 'space-weight association of response codes': SWARC), indicating a possible spatial representation for this physical dimension.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were approved by the Ethics Committee for Psychological

Research at the University of Padova, and were in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix

The strength of the SQUARC effect was computed through the following equation:

$$\begin{aligned}\mathrm{SQE}_i = {} & \left[\mathrm{RT}_i(\text{heavy, left}) - \mathrm{RT}_i(\text{heavy, right})\right] \\ & + \left[\mathrm{RT}_i(\text{light, right}) - \mathrm{RT}_i(\text{light, left})\right]\end{aligned}$$

where SQE_i stands for the strength of the SQUARC effect for the ith participant. RT_i(heavy, left) and RT_i(heavy, right) stand for the average RTs for the ith participant when she/he responded to 'heavier' target words with the left-side key and the right-side key, respectively. RT_i(light, right) and RT_i(light, left) stand for the average RTs for the ith participant when she/he responded to 'lighter' target words with the right-side key and the left-side key, respectively. The SQE_i increases with the strength of the association between 'heavier' ('lighter') words and the right-side (left-side) response. A negative SQE_i would indicate the presence of an inverted SQUARC effect.

References

Baayen RH, Davidson DJ, Bates DM (2008) Mixed-effects modelling with crossed random effects for subjects and items. J Mem Lang 59:390–412. https://doi.org/10.1016/j.jml.2007.12.005

Baroni M, Bernardini S, Ferraresi A, Zanchetta E (2009) The WaCky wide web: a collection of very large linguistically processed web-crawled corpora. Lang Resour Eval 43:209–226. https://doi.org/10.1007/s10579-009-9081-4

Bates D, Maechler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48. https://doi.org/10.18637/jss.v067.i01

Bruzzi E, Talamini F, Priftis K, Grassi M (2017) A SMARC effect for loudness. iPerception 8:2041669517742175. https://doi.org/10.1177/2041669517742175

Brysbaert M, Stevens M (2018) Power analysis and effect size in mixed effects models: a tutorial. J Cogn 1:9. https://doi.org/10.5334/joc.10

Buckingham G (2014) Getting a grip on heaviness perception: a review on weight illusions and their probable causes. Exp Brain Res 232:1623–1629. https://doi.org/10.1007/s00221-014-3926-9

Buckingham G, MacDonald A (2016) The weight of expectation: implicit, rather than explicit, prior expectations drive the size–weight illusion. Q J Exp Psychol 69:1831–1841. https://doi.org/10.1080/17470218.2015.1100642

Buckingham G, Ranger NS, Goodale MA (2011) The material–weight illusion induced by expectations alone. Atten Percept Psychophys 73:36–41. https://doi.org/10.3758/s13414-010-0007-4

Casasanto D (2009) Embodiment of abstract concepts: good and bad in right-and left-handers. J Exp Psychol Gen 138:351–367. https://doi.org/10.1037/a0015854

Chang S, Cho YS (2015) Polarity correspondence effect between loudness and lateralized response set. Front Psychol 6:683. https://doi.org/10.3389/fpsyg.2015.00683

Cohen Kadosh R, Lammertyn J, Izard V (2008) Are numbers special? An overview of chronometric, neuroimaging, developmental, and comparative studies of magnitude representation. Prog Neurobiol 84:132–147. https://doi.org/10.1016/j.pneurobio.2007.11.001

Dehaene S (1997) The number sense: how the mind creates mathematics. Oxford University Press, New York

Dehaene S, Dupoux E, Mehler J (1990) Is numerical comparison digital? Analogic and symbolic effects in two-digit number comparison. J Exp Psychol Hum Percept Perform 16:626–641. https://doi.org/10.1037/0096-1523.16.3.626

Dehaene S, Bossini P, Giraux P (1993) The mental representation of parity and number magnitude. J Exp Psychol Gen 122:371–396. https://doi.org/10.1037/0096-3445.122.3.371

Di Rosa E, Bardi L, Umiltà C, Masina F, Forgione M, Mapelli D (2017) Transcranial direct current stimulation (tDCS) reveals a dissociation between SNARC and MARC effects: implication for the polarity correspondence account. Cortex 93:68–78. https://doi.org/10.1016/j.cortex.2017.05.002

Dijker AJ (2014) The role of expectancies in the size-weight illusion: a review of theoretical and empirical arguments and a new explanation. Psychon Bull Rev 21:1404–1414. https://doi.org/10.3758/s13423-014-0634-1

Ellis RE, Lederman SJ (1999) The material-weight illusion revisited. Percept Psychophys 61:1564–1576. https://doi.org/10.3758/BF03213118

Fias W, Brysbaert M, Geypens F, d'Ydewalle G (1996) The importance of magnitude information in numerical processing: evidence from the SNARC effect. Math Cogn 2:95–110. https://doi.org/10.1080/135467996387552

Fischer MH (2006) The future of the SNARC could be the STARK…. Cortex 42:1066–1068. https://doi.org/10.1016/S0010-9452(08)70218-1

Fischer MH, Shaki S (2011) Predilection or preconception? A reply to Treccani and Umiltà. Brain Cogn 75:316–318. https://doi.org/10.1016/j.bandc.2010.11.011

Fischer MH, Shaki S, Cruise A (2009) It takes just one word to quash a SNARC. Exp Psychol 56:361–366. https://doi.org/10.1027/1618-3169.56.5.361

Fischer MH, Mills RA, Shaki S (2010) How to cook a SNARC: number placement in text rapidly changes spatial-numerical associations. Brain Cogn 72:333–336. https://doi.org/10.1016/j.bandc.2009.10.010

Flanagan JR, Bittner JP, Johansson RS (2008) Experience can change distinct size-weight priors engaged in lifting objects and judging their weights. Curr Biol 18:1742–1747. https://doi.org/10.1016/j.cub.2008.09.042

Fumarola A, Prpic V, Da Pos O, Murgia M, Umiltà C, Agostini T (2014) Automatic spatial association for luminance. Atten Percept Psychophys 76:759–765. https://doi.org/10.3758/s13414-013-0614-y

Gevers W, Reynvoet B, Fias W (2003) The mental representation of ordinal sequences is spatially organized. Cognition 87:B87–B95. https://doi.org/10.1016/S0010-0277(02)00234-2

Gevers W, Verguts T, Reynvoet B, Caessens B, Fias W (2006) Numbers and space: a computational model of the SNARC effect. J Exp Psychol Hum Percept Perform 32:32–44. https://doi.org/10.1037/0096-1523.32.1.32

Hartmann M, Mast FW (2017) Loudness counts: interactions between loudness, number magnitude, and space. Q J Exp Psychol 70:1305–1322. https://doi.org/10.1080/17470218.2016.1182194

Herrera A, Macizo P, Semenza C (2008) The role of working memory in the association between number magnitude and space. Acta Psychol 128:225–237. https://doi.org/10.1016/j.actpsy.2008.01.002

Holmes KJ, Lourenco SF (2013) When numbers get heavy: is the mental number line exclusively numerical? PLoS ONE 8:e58381. https://doi.org/10.1371/journal.pone.0058381

Krause F, Bekkering H, Lindemann O (2013) A feeling for numbers: shared metric for symbolic and tactile numerosities. Front Psychol 4:7. https://doi.org/10.3389/fpsyg.2013.00007

Kuznetsova A, Brockhoff PB, Christensen RHB (2017) lmerTest package: tests in linear mixed effects models. J Stat Softw 82:1–26. https://doi.org/10.18637/jss.v082.i13

Lenth RV (2016) Least-squares means: the R package lsmeans. J Stat Softw 69:1–33. https://doi.org/10.18637/jss.v069.i01

Moyer RS, Landauer TK (1967) Time required for judgments of numerical inequality. Nature 215:1519–1520. https://doi.org/10.1038/2151519a0

Myachykov A, Scheepers C, Fischer MH, Kessler K (2014) TEST: a tropic, embodied, and situated theory of cognition. Top Cogn Sci 6:442–460. https://doi.org/10.1111/tops.12024

Nuerk HC, Wood G, Willmes K (2005) The universal SNARC effect: the association between number magnitude and space is amodal. Exp Psychol 52:187–194. https://doi.org/10.1027/1618-3169.52.3.187

Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9:97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Proctor RW, Cho YS (2006) Polarity correspondence: a general principle for performance of speeded binary classification tasks. Psychol Bull 132:416–442. https://doi.org/10.1037/0033-2909.132.3.416

Ren P, Nicholls MER, Ma Y, Chen L (2011) Size matters: non-numerical magnitude affects the spatial coding of response. PLoS ONE 6:e23553. https://doi.org/10.1371/journal.pone.0023553

Ross HE (1969) When is a weight not illusory? Q J Exp Psychol 21:346–355. https://doi.org/10.1080/14640746908400230

Schwarz W, Müller D (2006) Spatial associations in number-related tasks: a comparison of manual and pedal responses. Exp Psychol 53:4–15. https://doi.org/10.1027/1618-3169.53.1.4

Sellaro R, Treccani B, Job R, Cubelli R (2015) Spatial coding of object typical size: evidence for a SNARC-like effect. Psychol Res 79:950–962. https://doi.org/10.1007/s00426-014-0636-7

Shaki S, Fischer MH (2018) Deconstructing spatial-numerical associations. Cognition 175:109–113. https://doi.org/10.1016/j.cognition.2018.02.022

Shaki S, Fischer MH, Petrusic WM (2009) Reading habits for both words and numbers contribute to the SNARC effect. Psychon Bull Rev 16:328–331. https://doi.org/10.3758/PBR.16.2.328

Shaki S, Petrusic WM, Leth-Steensen C (2012) SNARC effects with numerical and non-numerical symbolic comparative judgments: instructional and cultural dependencies. J Exp Psychol Hum Percept Perform 38:515–530. https://doi.org/10.1037/a0026729

Treccani B, Umiltà C (2011) How to cook a SNARC? Space may be the critical ingredient after all: a comment on Fischer, Mills, and Shaki (2010). Brain Cogn 75:310–315. https://doi.org/10.1016/j.bandc.2010.11.006

Vallesi A, Binns MA, Shallice T (2008) An effect of spatial- temporal association of response codes: understanding the cognitive representations of time. Cognition 107:501–527. https://doi.org/10.1016/j.cognition.2007.10.011

van Dijck JP, Fias W (2011) A working memory account for spatial-numerical associations. Cognition 119:114–119. https://doi.org/10.1016/j.cognition.2010.12.013

Vicovaro M, Burigana L (2017) Contribution of surface material and size to the expected versus the perceived weight of objects. Atten Percept Psychophys 79:306–319. https://doi.org/10.3758/s13414-016-1212-6

Walsh V (2003) A theory of magnitude: common cortical metrics of time, space and quantity. Trends Cogn Sci 7:483–488. https://doi.org/10.1016/j.tics.2003.09.002

Walsh V (2015) A theory of magnitude: the parts that sum of numbers. In: Cohen Kadosh R, Dowker A (eds) The Oxford handbook of numerical cognition. Oxford University Press, Oxford, pp 552–565

Westfall J, Kenny DA, Judd CM (2014) Statistical power and optimal design in experiments in which samples of participants respond to samples of stimuli. J Exp Psychol Gen 143:2020–2045. https://doi.org/10.1037/xge0000014

Winter B, Matlock T, Shaki S, Fischer MA (2015) Mental number space in three dimensions. Neurosci Biobehav Rev 57:209–219. https://doi.org/10.1016/j.neubiorev.2015.09.005

Wood G, Willmes K, Nuerk HC, Fischer MH (2008) On the cognitive link between space and number: a meta-analysis of the SNARC effect. Psychol Sci Q 50:489–525. https://doi.org/10.1027/1618-3169.52.3.187

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