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SNARC-like compatibility effects for physical and phenomenal magnitudes: A study on visual illusions

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Abstract

Both numerical and non-numerical magnitudes elicit similar Spatial-Numerical Association of Response Codes (SNARC) effects, with small magnitudes associated with left hand responses and large magnitudes associated with right hand responses (Dehaene, Bossini, Giraux, 1993). In the present study, we investigated whether the phenomenal size of visual illusions elicits the same SNARC-like effect revealed for the physical size of pictorial surfaces. Four experiments were conducted by using the Delboeuf illusion (Experiment 1) and the Kanizsa triangle illusion (Experiments 2, 3 & 4). Experiment 1 suggests the presence of a SNARC-like compatibility effect for the physical size of the inducers, while this effect was not revealed for the phenomenal size of the induced elements, possibly masked by a stronger effect of the inducers. A SNARC-like effect for the phenomenal size of the Kanizsa triangle was revealed when participants directly compared the size of the triangles (Experiment 4). Conversely, when participants performed an indirect task (orientation judgment), the SNARC-like effect was present neither for the illusory nor for the physical displays (Experiments 2 & 3). The effect revealed for the size of illusory triangles was comparable to that of real triangles with physical contours, suggesting that both phenomenal and physical magnitudes similarly elicit SNARC-like effects.

Keywords: geometrical visual illusion; physical size and illusory size;; SNARC; Kanizsa' triangle illusion; Delboeuf illusion.

1. INTRODUCTION

A wide number of studies have shown a strict relationship between number magnitude and space. The Spatial-Numerical Association of Response Codes effect (SNARC - Dehaene, Bossini & Giraux, 1993) provides compelling evidence that numbers are spatially coded along a left-to-right mental number line (Restle, 1970). Dehaene et al. (1993) showed that participants are faster in responding to relatively smaller numbers with a left key-press, and to relatively larger numbers with a right key-press. The authors suggest that the SNARC effect would be the result of a direct correspondence between a mental number line representation and the execution of responses in the external space (for alternative accounts see Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Proctor & Cho, 2006).

The SNARC effect was demonstrated to be robust across type of task, as it has been found in both direct tasks where number magnitude was task relevant (e.g., magnitude comparison; Dehaene, Dupoux, & Mehler, 1990) and in indirect tasks where number magnitude was task irrelevant (e.g., line orientation judgment, Fias, Lauwereyns & Lammertyn, 2001). Furthermore, the SNARC effect has been shown to be robust to the format (symbolic vs. non-symbolic) of the magnitude's attribute. Indeed, it extends also to non-symbolic magnitudes, such as physical size (Ren et al., 2011), luminance (Ren et al., 2011; Fumarola et al., 2014), angle magnitude (Fumarola et al., 2016) and loudness (Hartman & Mast, 2016). In these cases, the effect is referred to as SNARC-like effect.

This behavioral similarity in the processing of magnitude information conveyed by symbolic and non-symbolic stimuli suggests the existence of a common mental representation of quantity (Dehaene, Dehaene-Lambertz, & Cohen, 1998). One study in particular showed that a brain site in the intraparietal sulcus (IPS) is specifically responsive when two stimuli are quantitatively compared, irrespective of magnitude format, providing evidence of a common mechanism for representing magnitude (Fias, Lammertyn, Reynvoet, Dupont & Orban, 2003).

The idea of a common mechanism for magnitude processing is the core of the ATOM model (Walsh, 2003; Buetti & Walsh, 2009), which constitutes a theoretical framework for the different SNARC-like compatibility effects. The model suggests that numbers, space, time and other non-numerical quantities are processed by a common generalized magnitude system devoted to action. This system is suggested to be in the parietal cortex. The ATOM model predicts that the SNARC effect generalizes to SQUARC (Spatial-Quantity Association of Response Codes) effects. On such a basis, both numerical and non-numerical quantities are associated to space and should thus elicit a similar SNARC-like compatibility effects.

This study focuses on a specific type of non-numerical magnitude, that is, the size of pictorial surfaces. A previous study (Ren et al., 2011, Experiment 2) showed that the physical size of filled disks elicits a SNARC-like effect. In Ren et al.'s study, participants judged the physical size of two disks of diameters by using a left/right response key. The disks were presented sequentially in the center of the screen and participants judged whether the second disk was physically smaller or larger than the first one. Results showed an interaction between the diameter of the disks and the response key, suggesting that physically smaller surfaces are associated with the left space, while physically larger surfaces are associated with the right space.

In many circumstances, however, the physical size of an object or of a pictorial surface could differ from its perceived size. Consider, for instance the moon illusion (Kaufman & Rock, 1962; Rock & Kaufman, 1962): the size of the moon seems to change when our satellite is in different positions in the sky; namely it appears larger near the horizon and smaller at the zenith. Similarly, in the Ebbinghaus/Titchener (Ebbinghause, 1902; Titchener, 1905) and Delboeuf size-contrast (Delboeuf, 1865) illusions a target disk appears smaller/larger when surrounded by larger/smaller inducers, respectively (see Figure 1 for an example of the Delboeuf illusion). In these cases, the presence of the inducers affects the perception of size, and thus magnitude, even though the actual size is unaltered.

In other cases, illusory figures are perceived to have similar characteristics to pictorial surfaces with physical contours. For example, in the Kanizsa's triangle illusion (1955), illusory contours that bound a perceptually integrated surface with a well-defined geometrical shape and size are characterized by their visibility due to the arrangements of partially occluded inducers. Such a visibility has been demonstrated by different studies, showing that the luminance of the illusory form is perceived differently from the one of the background (Meyer & Petry, 1987; Coren, Porac & Theodor, 1986).

Although most studies focused on how illusory figures are perceived, a line of research investigated how visual illusions affect motor actions. Conflicting evidence lead to an passionate debate between two opposite views. One suggests that visual illusions affect perception more than action, thus proposing a dissociation between perception and action processes (Agliotti, DeSouza & Goodale, 1995; Ganel, Tanzer & Goodale, 2008; Goodale, Milner, Jackobson & Carey, 1991; Goodale et al., 1994; Haffenden, Schiff & Goodale, 2001). The other point of view claims against the existence of a dissociation between perception and action with visual illusions (Franz, 2001; Franz & Gegenfurtner, 2008; Franz, Gegenfurtner, Bülthoff & Fahle, 2000). Although many of the above-mentioned studies failed to show a clear dissociation under controlled settings, a few examples in the literature seem to suggest that perception and action can be dissociated when the size of real and illusory objects is contrasted (e.g., Ganel, Tanzer & Goodale, 2008). The perception versus action dispute appears not to be definitively settled and this debate constitutes an additional rationale for our study.

To our knowledge, no previous study investigated visual illusions by using simple button press movements in SNARC-like compatibility tasks. Studies that investigated SNARC-like compatibility effects for non-numerical magnitudes focused exclusively on physical rather than phenomenal features of the stimuli (Ren et al., 2011), thus neglecting to investigate visual illusions. The aim of the present study isto investigate whether phenomenal magnitudes elicit SNARC-like compatibility effects similarly to physical magnitudes. In particular, we were interested in investigating whether the phenomenal size of visual illusions elicits analogous SNARC-like effects as the physical size of pictorial surfaces (Ren et al. 2011, Experiment 2).

In Experiment 1, we employed a direct task that required simultaneous comparison of the phenomenal size of two physically identical surfaces. For this purpose, we chose the Delboeuf size-contrast illusion (1865). In this illusion, two physically identical disks appear different in size due to the effect of surrounding inducers (*annuli*). We expected that, if the SNARC-like compatibility effect found for physical magnitudes extends also to phenomenal magnitudes, a response advantage would be found when the apparently smaller target disk is displayed on the left and the apparently larger target disk on the right. Conversely, if SNARC-like compatibility effects are specific to physical magnitudes and do not extend to phenomenal magnitudes, we predict a reversed pattern. Indeed, the physical size of task irrelevant inducers (*annuli*) should produce a response advantage for the display depicting the target surrounded by the smaller inducer on the left and the target surrounded by the larger inducer on the right.

In Experiment 2, 3 and 4, we employed the Kanizsa Triangle illusion (1955). In the illusory triangle condition, the configuration of the inducers was displayed to create an illusory triangle figure. The distance between the inducers was manipulated to create triangles of four different sizes and the orientation of the inducers was also manipulated in order to create triangles with an upward/downward vertex. In the control condition of Experiment 2, the same inducers were rotated by 180 degrees in order not to create any illusory figure. This manipulation allowed to present the same visual elements in both conditions.

In the control conditions of Experiment 3 and 4, we added a physical contour to the illusory triangles to measure participants' reaction to real triangles. In both Experiment 2 and 3, the task consisted in judging the spatial orientation (upward/downward) of the display, with Experiment 2 focusing on the position of inducers and Experiment 3 focusing on the actual orientation of the triangles. In Experiment 4, the task consisted in a direct comparison of the size of both illusory and real triangles. We expect that, if a SNARC-like compatibility effect is elicited by the size of illusory figures, smaller illusory triangles should be judged faster with a left key-press, and vice versa. Conversely, if a similar effect is found in the control conditions only, this should be ascribed exclusively to the physical properties of the inducers and triangles (i.e., physical size, distance).

To our knowledge, no study at present has investigated the SNARC-like effect for the phenomenal magnitude of visual illusions. Therefore, we put forward two hypotheses

1) *Phenomenal magnitude hypothesis*: if phenomenal magnitudes are spatially coded similarly to physical magnitudes, we expect that the phenomenal size of visual illusions would elicit a SNARC-like compatibility effect similarly to the physical size of pictorial surfaces.

2) *Physical magnitude hypothesis:* if phenomenal magnitudes are not spatially coded similarly to physical magnitudes, we expect that only the physical magnitudes of the inducers and real figures would elicit SNARC-like effects.

2. EXPERIMENT 1

In Experiment 1 we presented a Delboeuf size-contrast display with two target disks of the same size, each of which was surrounded by an *annulus* of different sizes (relatively small and large) used as inducer. Typically, in this display the target surrounded by the larger inducer appears smaller than the target surrounded by the smaller inducer (Delboeuf, 1865). In the display, the two targets surrounded by the inducers appeared simultaneously, one on the left and one on the right side of the screen. Based on the evidence provided by the SNARC-like compatibility effects for non-numerical magnitudes, and in particular from the study of Ren et al (2011), we formulated two main hypotheses. If phenomenal magnitudes do elicit SNARC-like compatibility effects similarly to physical magnitudes (phenomenal magnitude hypothesis), then we expect participants to respond faster to the display where the target perceived as smaller appears on the left side of the screen and the target perceived as larger appears on the right (Figure 1a – phenomenal magnitude compatibility). Alternatively, if the phenomenal magnitude of the targets does not elicit a SNARC-like compatibility effect, then the physical magnitude of the inducers should influence participants' response times (physical magnitude hypothesis). In this case, we expect participants to show the opposite response pattern, thus faster responses for the display where the physically smaller inducer appears on the left side of the screen and the larger inducer appears on the right (Figure 1b – physical magnitude compatibility).

Summarizing, the phenomenal magnitude hypothesis suggests faster response times for the display represented in Figure 1a (phenomenal magnitude compatibility), while the physical magnitude hypothesis suggests faster response times for the display represented in Figure 1b (physical magnitude compatibility). Hence, whilst the phenomenal magnitude condition refers to the perceived size of the targets, the physical magnitude condition refers to the physical size of the inducer.

Fig. 1 Based on the compatibility with a left-to-right magnitude representation, we named the two displays phenomenal magnitude compatibility (a) and physical magnitude compatibility (b) displays, respectively. Indeed, in display (a) the phenomenally smaller target is displayed on the left side of the screen while the phenomenally larger target is displayed to the right. In display (b) the physically smaller inducer is displayed on the left side of the screen while the physically larger inducer is displayed on the right.

2.1 Method

2.1.1 Participants. Eighteen participants were tested in Experiment 1. Sixteen were right-handed and two left-handed; all of them were used to the left-to-right writing direction. They had a mean age of 24.1 (*SD* = 4.7). Fourteen of the participants were female and four were male. All participants had normal or corrected-to-normal vision and were naive about the purpose of the experiment and the hypothesis being tested. Participants were all volunteer psychology students from the University of Trieste. Informed consent was obtained prior to participation in the experiment, which was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

2.1.2 Apparatus and stimuli. The experiment was created and controlled through the E-Prime software, version 2.0. Stimuli were displayed on a 24 inches calibrated monitor (Quato Intelli Proof 242 excellence), with a 1024 x 768 resolution. The PC was a Dell desk computer with Intel Core i5 (RAM: 4Gb). The Operating System was Microsoft Windows 7 64-bit Edition. A five button Serial Response Box, connected to the pc by means of a serial port, was used for collecting responses.

Stimuli consisted of four 800x600 bmp pictures representing four Delboeuf displays. In all the pictures two target disks were presented simultaneously, one on the left and one on the right side of the screen. The centres of the targets were equidistant from the centre of the screen and the closer lateral margins of the pictures. The diameter of the target measured 1.4 deg of visual angle and remained constant among all the pictures. Two sets of inducers with different sizes were used: a small inducers condition, in which the diameter of the small/large inducers were 2.1 and 4.2 deg of visual angle, respectively, and a large inducers condition in which the diameter of the small/large inducers were 2.8 cm and 8.4 deg of visual angle, respectively. Those values are clearer when reported in proportions. Indeed, in the small inducers condition the target's diameter was 2/3 and 1/3 of the small/large inducer's diameter, respectively, while in the larger inducers condition the target's diameter was 1/2 and 1/6 of the small/large inducer's diameter, respectively. In sum, we had four different displays: two sets (small and large inducers condition) for both phenomenal magnitude compatibility (Figure 1a) and physical magnitude compatibility (Figure 1b) displays.[1] All the stimuli are reported in Figure 3. The targets and background were black while the inducers were white.

2.1.3 Procedure. The experiment took place in a quiet, dimly lit room without environmental distractions. Participants were positioned in front of the PC. The midlines of the screen and the response box were aligned with the midline of the participant's body. The viewing distance was 60 cm. Participants were instructed to move as little as possible and were asked to position their left

[1]The displays shown in Figure 1 are in the large inducers condition.

index finger on the leftmost key and their right index finger on the rightmost key of the response box.

Each trial started with a fixation cross measuring 1 deg of visual angle presented for 300 ms, followed by an inter-stimulus interval (ISI) of 130 ms. Then the picture appeared and lasted until a response occurred or for a maximum of 2000 ms. The task required to compare the perceived size of the targets and to indicate which of the two targets appeared smaller or larger, in separate sessions. In the "detect the smaller target" session, participants were asked to press the leftmost key, with the ipsilateral hand, when the target perceived as smaller appeared on the left side of the screen. In the "detect the larger target" session, the task was to detect which target appeared larger. This comparison procedure was adapted from Fias, Lammertyn, Reynvoet, Dupont and Orban (2003). The order of the two sessions was counterbalanced across participants. Each of the two sessions started with 8 practice trials (not considered for data analysis). Then, each of the four pictures was presented 10 times in random order during each session. This resulted in a total of 40 trials in each session. The inter-trial interval (ITI) was 1500 ms. Participants were allowed to take a short break between the two sessions, otherwise they could continue with the experiment. Both speed and accuracy were stressed in the instructions.

2.1.4 Experimental design. We employed a 2x2x2 within subjects design. The following variables were systematically manipulated: Display (phenomenal vs. physical magnitude compatibility), Inducers Size (small vs. large), and Response Location (left vs. right). This last variable refers to the location of the correct response, which varied depending on the required task (i.e., indicating either the smaller or the larger target).

2.2 Data analysis and results

At first, we examined the occurrence of response errors and misses. Participants failed to respond before the deadline (0.2%) and committed errors (2.6%) in just a few cases. Thus, all the participants perceived the predicted illusion, that is, a smaller target within a larger inducer, and vice versa. Errors and misses were removed from the analysis. According to previous literature (Fias, Lauwereyns & Lammertyn, 2001), outlier RTs below 150 ms and above 1000 ms were also removed from the analysis (8.6%).

A repeated-measures ANOVA was run for Response Times (RTs). The results revealed a significant main effect of Inducers Size [$F(1,17) = 15.15$; $p < .001$; $\eta_p^2 = .47$], indicating a difference in the response latencies for small ($M = 619$ ms; $SE = 14$ ms) and large ($M = 579$ ms; $SE = 14$ ms) inducers' size. A main effect of Display was also found [$F(1,17) = 4.8$; $p < .05$; $\eta_p^2 = .22$], indicating a difference in the response latencies for phenomenal ($M = 610$ ms; $SE = 14$ ms) and physical ($M = 588$ ms; $SE = 15$ms) magnitude compatibility displays (Figure 2). Conversely, the main effect of Response Location was not significant [$F(1,17) = 0.11$; $p = .75$]. Moreover, the results revealed a value approaching statistical significance for the interaction Inducers Size x Display [$F(1,17) = 3.75$; $p = .069$; $\eta_p^2 = .18$], whilst the interactions Inducers Size x Response Location [$F(1,17) = 0.06$; $p = .82$], Display x Response Location [$F(1,17) = 0.05$; $p = .82$] and Inducers Size x Display x Response Location [$F(1,17) = 0.03$; $p = .87$] were all not significant.

Fig. 2 Results for the phenomenal magnitude compatibility and the physical magnitude compatibility displays in Experiment 1. Error bars represent standard errors of the mean.

To better explore the role of the inducers' size, we separately analyzed the data for the small and large inducers conditions. Two separate repeated-measures ANOVAs were run for

Response Times (RT), with a 2x2 (Display x Response location) design. The results for the larger inducers condition revealed non-significant main effects for both Display [$F(1,17) = 0.47$; $p = .50$] (Figure 3a) and Response Location [$F(1,17) = 0.0$; $p = .95$]. The interaction Display x Response Location was also non-significant [$F(1,17) = 0.07$; $p = .80$].

Fig. 3 Results for the phenomenal and physical magnitude compatibility displays in the large (a) and small (b) inducers condition (Experiment 1). Error bars represent standard errors of the mean.

Conversely, the results for the small inducers condition revealed a significant main effect for Display [$F(1,17) = 6.97$; $p < .05$; $\eta_p^2 = .29$], indicating a difference in the response latencies for phenomenal (*M* = 637 ms; *SE* = 19 ms) and physical (*M* = 600 ms; *SE* = 21 ms) magnitude compatibility displays (Figure 3b). Both the main effect of Response Location [$F(1,17) = 0.13$; $p = .72$] and the interaction Display x Response Location were not-significant [$F(1,17) = 0.03$; $p = .87$].

2.3 Discussion

In Experiment 1 we aimed to assess whether the phenomenal size of the target disks elicits a SNARC-like compatibility effect in a Delboeuf size-contrast display. Alternatively, we hypothesized that the physical size of the inducers could influence participants' response latencies. Thus, phenomenal and physical magnitude hypotheses were opposed.

Overall, response latencies were faster for the physical magnitude compatibility display (Figure 1b) than for the phenomenal magnitude compatibility display (Figure 1a), see Figure 2. This result supports the physical magnitude hypothesis against the phenomenal magnitude hypothesis. No interaction between display and response location was found revealing that the main effect of the display was consistent through task instructions (i.e., indicate which of the targets appeared smaller or larger, by pressing the leftmost or the rightmost keys).

Furthermore, results show that participants were faster to perform the comparison task in the large compared to the small inducers condition, suggesting that the illusion was stronger and the task easier to complete. We separately analyzed the small/large inducers conditions and we found that the effect was significant only for the small inducers condition, where response latencies were generally slower. This evidence is supported by previous studies which revealed that the size of the SNARC effect became larger when the time needed to reach a motor response became longer (Gevers, Verguts, Reynvoet, Caessens & Fias, 2006; Wood, Willmes, Nuerk & Fischer, 2008). Indeed, the dual route model of the SNARC effect (Gevers et al., 2006) states that a stronger effect should be observed with slower responses because the unconditional route has more time to interfere with the selection of a response button.

From a broader perspective, the results of this experiment are consistent with the evidence provided by Ren et al. (2011) - that the physical size of pictorial surfaces elicits a SNARC-like effect, with relatively small magnitudes associated with the left space and relatively large magnitudes associated with the right space. Furthermore, since participants were required to compare the size of the targets and not the inducers, our results suggest that a SNARC-like effect can be elicited also by task irrelevant physical magnitudes. Conversely, no evidence supports the idea that phenomenal magnitudes can be spatially coded similarly to physical magnitudes.

However, in the Delboeuf size-contrast and in other similar displays (e.g., the Ebbinghaus/Titchener display) it is impossible to avoid the effect of the inducers’ physical size and to study the SNARC-like effect for the phenomenal size of the targets separately. Indeed, the phenomenal size of physically identical targets is induced by the different physical size of the inducers. Therefore, we cannot exclude that a SNARC-like effect for the phenomenal size of the targets exists but that it is masked by a stronger and opposite effect of the physical size of the inducers. However, our results clearly show that when phenomenal and physical magnitudes are opposed, the physical magnitude prevails.

To disentangle the possible effects of the phenomenal magnitude from the one of the physical magnitude on SNARC-like compatibility effects, we run a second experiment by using the Kanizsa triangle illusion. Differently from the Delboeuf size-contrast display, the Kanizsa triangle illusion allows for the size manipulation of the illusory figure whilst keeping the physical size of the inducers unaltered.

3. EXPERIMENT 2

In Experiment 2 we employed a set of manipulations of the famous display proposed by Kanizsa (1955) in which six inducers (three disks with a missing slice of 60° and three lines) were properly arranged in order to induce the perception of an illusory triangle (Figure 4 – Kanizsa illusory triangle). By manipulating the distance between the inducers, we manipulated the size of the illusory triangle. Conversely, by rotating the disks in a way that the missing slice would be oriented externally, the illusory triangle disappears (Figure 4b – Non-Kanizsa control). Thus, by manipulating the distance of the inducers we have been able to coincidently manipulate the physical (distance) and the phenomenal (area of the triangle) magnitudes in the triangle display, while we exclusively manipulate the physical magnitude (distance) in the Non-Kanizsa control display. It is noteworthy that, differently from Experiment 1, in this case the physical size of the inducers is unaltered. Furthermore, the exact same elements are present in both illusory triangles and control figures; the only difference is the presence of a triangle with illusory contours in the illusory triangle condition. Therefore, these two figures could be considered equal from a physical point of view but highly dissimilar from a phenomenal perspective.

In Experiment 2 we decided to use an orientation task since previous studies (Fias, Lauwereyns & Lammertyn, 2001; Prpic, Fumarola, De Tommaso, Luccio, Murgia & Agostini, 2016; Mitchell, Bull & Cleland, 2012) showed that the processing of orientation interferes with both numerical and non-numerical magnitudes by eliciting a consistent SNARC-like effect. Indeed, orientation strongly relies on the parietal cortex where the magnitude system is located (Bueti & Walsh, 2009; Piazza et al., 2007; Van Opstal & Verguts, 2013). Furthermore, the orientation task used in this experiment allows us to present each stimulus in the middle of the screen and to use the response location (leftward vs. rightward key-press) as the only criterion variable. This makes the design of Experiment 2 more in line with the ones classically used to study SNARC and SNARC-like effects.

We hypothesized that if the phenomenal size of the illusory triangle elicits a SNARC-like effect, such an effect should be absent (or reduced) in the control display where no illusory surfaces are perceived (phenomenal magnitude hypothesis). Conversely, if a SNARC-like effect is elicited exclusively by the physical distance between the inducers, this effect should be similarly revealed in both triangle and control displays (physical magnitude hypothesis).

3.1 Method

3.1.1 Participants. Seventeen participants took part in Experiment 2. Sixteen were right-handed and one left-handed; all of them were used to the left-to-right writing direction. They had a mean age of 23.4 (*SD* = 3.6). Thirteen of the participants were female and four were male. All participants had normal or corrected-to-normal vision and were naive about the purpose of the experiment and the hypothesis being tested. Participants were all volunteer psychology students from the University of Trieste. Informed consent was obtained prior to participation in the experiment, which was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

3.1.2 Apparatus and stimuli. Apparatus was the same as in Experiment 1.

Stimuli consisted of sixteen 800x600 bmp pictures representing Kanizsa triangle and Non-Kanizsa control displays, with white inducers against a black background. Both displays were represented in two differently oriented versions, one with two disks on the top and a disk on the bottom, and vice versa. Moreover, in all the versions of the displays the distance between the inducers was manipulated resulting in four distance levels between the disks, respectively 2.9, 4.3, 7.2 and 8.6 deg of visual angles. The displays were presented one by one in the middle of the screen. The diameter of the inducer disks measured 2.9 deg of visual angle while the length of the inducer lines was 1.4 deg of visual angle. See Figure 4 for an example of the stimuli.

3.1.3 Procedure. The experimental setting and the participants' position were the same as in the previous experiment. As in Experiment 1, each trial started with a fixation cross presented for 300 ms, followed by an inter-stimulus interval (ISI) of 130 ms. Then the pictures appeared and lasted until a response occurred or for a maximum of 2000 ms.

The task consisted of judging the orientation of the presented displays and the experiment was divided into two sessions. In the first, participants were asked to press the leftmost key, with their left hand, when the display was oriented with a single inducer disk above and two inducer disks below on the screen. Conversely, they were asked to press the rightmost key, with their right hand, when the display was oriented with a single inducer disk below and two inducer disks above on the screen. In the second session, the assignment was reversed. The order of the two sessions was counterbalanced across participants. Each of the two sessions started with 16 practice trials (not considered for data analysis). Then, each stimulus was presented 5 times in random order. This resulted in a total of 80 trials in each session. The inter-trial interval (ITI) was 1500 ms. Participants were allowed to take a short break between the two sessions, otherwise they could continue with the experiment. Both speed and accuracy were stressed in the instructions.

Fig. 4 Example of the stimuli used in the study. Kanizsa illusory triangle and Non-Kanizsa control were used in Experiment 2, while Kanizsa illusory triangle and Real triangle were used in Experiments 3 and 4.

3.1.4 Experimental design. We employed a 2x2x2x4 within subjects factorial design. The following variables were systematically manipulated: Figure (Kanizsa illusory triangle vs. Non-Kanizsa control), Orientation (upward vs. downward), Response Location (left vs. right) and Inducers' Distance (2.9, 4.3, 7.2 and 8.6 deg of visual angles).

3.2 Data analysis and results

Errors (1.9%) and misses (0.2%) were removed from the analysis as well as outlier RTs below 150 ms and above 1000 ms (2.4%).

A repeated-measures ANOVA was run for mean response times (RTs). The results revealed a significant main effect of Response location [$F(1,16) = 7.34$; $p < .05$; $\eta^2 = .31$] and Inducers' Distance [$F(3,48) = 2.86$; $p < .05$; $\eta^2 = .15$].The main effects of Figure [$F(1,16) = 3.36$; $p = .09$] and Orientation [$F(1,16) = .14$; $p = .72$] were non-significant. The only significant interaction was

Orientation x Inducers' Distance [$F(3,48) = 4.73$; $p < .01$; $\eta^2 = .23$], while Inducers' Distance x Response Location [$F(3,48) = .72$; $p = .55$] and Inducers Distance x Response Location x Figure [$F(3,48) = 0.78$; $p = .51$], as well as all the other interactions, were non-significant. The lack of a significant interaction between Inducers' Distance and Response Location suggests the absence of a SNARC-like effect.

The presence of a SNARC-like effect was further assessed by means of a regression analysis of repeated measures as described by Lorch and Myers (1990). For the advantages of this analysis see Fias, Brysbaert, Geypens, & D'Ydewalle (1996). Separate analyses were performed for the illusory triangle and control conditions. The predictor variable was the Inducers' distance, whereas the criterion variable was the difference in RT (dRTs) of the right hand and left hand: dRTs = RT(right hand) - RT(left hand). Positive dRTs indicate faster responses with the left key-press, whereas negative dRTs indicate faster responses with the right key-press. In the first step, for each participant the median RT of the correct responses was computed for each inducers distance, separately for left- and right-hand responses. On the basis of these medians, dRT was computed by subtracting the median RT of left-hand responses from the median RT of right-hand responses. In the second step, a regression equation was computed for each participant with the inducers distance as the predictor variable. In the third step, a one-sample t-test was performed to verify whether beta regression weights of the group deviated significantly from zero.

The analysis of dRTs revealed that the regression slopes were significantly different from zero for the control condition [$t(16) = -2.8$; $p < .05$] but not for the triangle condition [$t(16) = .76$; $p = .46$]. This result shows a relative left key-press advantage for processing small inducer distances (i.e., 2.9 and 4.3 deg of visual angles) and a relative right key-press advantage for large inducer distances (i.e., 7.2 and 8.6 deg of visual angles) in the Non-Kanizsa control condition. In order to directly compare the slopes, a paired sample t-test was performed on the beta regression weights in the control and triangle conditions. The results indicate that the two conditions differ significantly [$t(16) = 2.42$; $p < .05$], suggesting that a SNARC-like effect was elicited only in the control condition (Figure 5).

Fig. 5 Mean differences of the median RTs right hand – RTs left hand as a function of inducers' distance in Experiment 2. Red diamonds represent the triangle condition, while black disks represent the control condition. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean.

3.3 Discussion

The aim of Experiment 2 was to investigate whether the phenomenal size of an illusory surface (i.e., the illusory triangle; Kanizsa, 1955) elicits a SNARC-like compatibility effect during an orientation task. We hypothesized that if such effect is elicited by the illusory triangle's surface, then it should be absent (or reduced) in the control condition where no illusory surfaces are perceived (phenomenal magnitude hypothesis). Conversely, if a SNARC-like effect is elicited exclusively by the physical distance between the inducers, this effect should be present also in the control condition (physical magnitude hypothesis).

The analyses revealed contradictory results since a repeated-measures ANOVA failed to show a significant SNARC-like effect, while a regression analysis indicated a significant SNARC-like effect for the control but not for the triangle condition. According to the results of the regression analysis, since the phenomenal size of the illusory triangle appeared not to elicit a SNARC-like effect, our evidence seems to oppose the phenomenal magnitude hypothesis. Conversely, in the control condition a SNARC-like pattern was revealed with participants showing faster left key-press responses when the inducers were relatively close and faster right key-press responses when the inducers were relatively far. This suggests that a physical magnitude (distance) can elicit a SNARC-like effect, further supporting the physical magnitude hypothesis, but at the same time raising the question of why the same response pattern was not found in the triangle condition.

Indeed, the presence of a SNARC-like effect in the control condition is not surprising per se, whereas the concurrent absence of a similar effect for the triangle condition was highly unexpected. It is relevant to highlight that our task instructions made explicit reference only to the position of the inducers, while the word “triangle” was never mentioned. Therefore, one possibility is that in our task the instructions enhanced the saliency of the control figures. Indeed, if from a physical point of view both control and triangle figures can be considered as almost identical (the only objective discrepancy is that the inducer disks differ 180° in orientation), from a phenomenal point of view, these two figures are perceived in substantially different way. Indeed, in the triangle condition people usually report to see a well-defined triangle, while in the control condition people just report to see three disks with a missing slice and three lines (i.e., the inducers). Therefore, in the triangle condition the illusory triangle is the most salient object in the display and it prevails on the inducers. Conversely, in the control condition only the inducers are perceived and therefore they become the only salient objects in the display. Thus, one possible interpretation of this result is that a SNARC-like effect is elicited exclusively by physical magnitudes (i.e., physical distance) when this dimension is salient (control condition). Conversely, it is not elicited when physical magnitudes are not salient because an illusory figure prevails over the inducers and their properties (triangle condition).

However, we should be cautious in the interpretation of these results since the ANOVA showed no evidence of a SNARC-like effect in either the conditions. Adopting a stricter criterion, , a reliable SNARC-like effect should be found in both the analysis, the ANOVA and the regression (see Lidji, Kolinsky, Lochy, & Morais, 2007 and Nuerk, Wood & Willmes, 2005 who used a similar approach). Furthermore, the lack of a SNARC-like effect in the illusory triangle condition is difficult to interpret without comparing the results with a condition where real triangles with physical contours are displayed. In order to do so, we ran a third experiment by using the same illusory figures but by adopting real triangles as control stimuli.

4. EXPERIMENT 3

Experiment 3 replicates Experiment 2 but the control figures were modified together with the instructions. The control figures in Experiment 3 consisted of "real" triangles created by adding a physical contour (thin white line) to the illusory contour of the Kanizsa illusory triangles. This manipulation allowed for the direct comparison of the SNARC-like effect for real vs. illusory triangles. Because of this manipulation, we could modify also the task instructions, by moving the focus from the inducers (Exp. 2) to the triangles (Exp. 3), during an orientation judgment task. Indeed, in Experiment 3 participants were explicitly required to compare the orientation (upward vs. downward) of both illusory and real triangles.

We hypothesized that if the phenomenal size of the illusory triangle elicits a SNARC-like effect, the same effect should be present in both illusory and real triangles (phenomenal magnitude hypothesis). Conversely, if a SNARC-like effect is elicited exclusively by the size of pictorial figures with physical contours, this effect should be revealed only for real triangles but not for illusory triangles (physical magnitude hypothesis).

4.1 Method

4.1.1 Participants. Twenty-three participants took part in Experiment 3. Twenty-two were right-handed and one left-handed; all of them were used to the left-to-right writing direction. They had a mean age of 25.1 (*SD* = 3.1). Seventeen of the participants were female and six were male. All participants had normal or corrected-to-normal vision and were naive about the purpose of the experiment and the hypothesis being tested. Participants were all volunteer psychology students from the University of Trieste. Informed consent was obtained prior to participation in the experiment, which was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

4.1.2 Apparatus and stimuli. Apparatus was the same as in Experiment 2. Stimuli representing Kanizsa illusory triangles were the same as in Experiment 2, while control stimuli consisted of real triangles with physical contours. The inducer disks presented for the illusory triangles were maintained in the control figures, while the inducer lines were removed. Another set of lines were added in the control figures in order to connect the inducer disks, creating the physical contours of the control triangles. See Figure 4 for an example of the stimuli.

4.1.3 Procedure. The experimental setting and the participants' position were the same as in the previous experiments.

The task consisted in judging the orientation of both illusory and real triangles (vertex upward or downward) in two experimental blocks. The instructions' focus was thus changed from the inducers (Exp. 2) to the triangles (Exp. 3). The order of the two blocks was counterbalanced across participants and participants had a five minutes break between the two blocks. Each block was then divided into two sessions. In the first one, participants were asked to press the leftmost key, with their left hand, when the triangle was oriented with the vertex upward and the rightmost key, with their right hand, when the triangle was oriented with the vertex downward. In the second session, the assignment was reversed. The order of the two sessions was counterbalanced across participants. Each block consisted in 8 images representing either illusory or real triangles of 4 different sizes and 2 orientations. The rest of the procedure was the same as in Experiment 2.

4.1.4 Experimental design. We employed a 2x2x2x4 within subjects factorial design. We examined four independent variables, three with two levels each and one with four levels: Condition Block (illusory vs. real triangle), Orientation (upward vs. downward), Response Location (left vs. right) and Inducers' Distance (2.9, 4.3, 7.2 and 8.6 deg of visual angles).

4.2 Data analysis and results

Errors (2.6%) and misses (0.4%) were removed from the analysis, as well as outlier RTs below 150 ms and above 1000 ms (1.7%).

A repeated-measures ANOVA was run for mean response times (RTs). The results revealed a significant main effect of Condition Block [$F(1,22) = 4.95$; $p < .05$; $\eta^2 = .18$], Orientation [$F(1,22) = 4.94$; $p < .05$; $\eta^2 = .18$] and Inducers' Distance [$F(3,66) = 3.69$; $p < .05$; $\eta^2 = .14$]. Conversely, the main effects of Response Location [$F(1,22) = 1.18$; $p = .29$] was non-significant. The interaction between Inducers Distance x Response Location [$F(3,66) = 1.35$; $p = .27$] and Inducers Distance x Response Location x Condition Block [$F(3,66) = 0.59$; $p = .62$] were both non-significant, as well as all the other interactions. The lack of a significant interaction between Inducers Distance and Response Location suggests the absence of a SNARC-like effect.

As for Experiment 2, a regression analysis of repeated measures was also conducted. Separate analyses were performed for the illusory and real triangles. The analysis of dRTs revealed that the regression slopes of both illusory [$t(22) = 0.53$; $p = .60$] and real [$t(22) = .22$; $p = .82$]

triangles were not significantly different from zero. Furthermore, a paired sample t-test performed on the beta regression weights of both illusory and real triangles indicates that the two conditions do not differ significantly [$t(22) = -.22$; $p = .83$] (Figure 6). The results of the regression analysis, thus, confirm those of the ANOVA, suggesting that a SNARC-like effect was not elicited by the size of illusory and real triangles during an orientation judgment task.

Fig. 6 Mean differences of the median RTs right hand – RTs left hand as a function of inducers' distance in Experiment 3. Red diamonds represent the triangle condition, while black disks represent the control condition. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean

4.3 Discussion

The aim of Experiment 3 was to replicate the Experiment 2 by using a different type of control figures, namely real triangles with physical contours. Compared to the previous experiment, we modified the task instructions by moving the focus from the inducers (Exp. 2) to the triangles (Exp. 3) during an orientation judgment task. The results of both ANOVA and regression analyses showed that a SNARC-like effect is elicited neither by the size of illusory triangles nor by that of real triangles.

These results support neither the phenomenal magnitude hypothesis nor the physical magnitude hypothesis, suggesting that the size of pictorial surfaces might not elicit a SNARC-like effect during an orientation judgment task. Evidence from previous studies indicates that an orientation judgment is effective in eliciting a SNARC effect with Arabic numbers (Fias et al., 2001), musical note values (Prpic et al., 2016) and non-symbolic numerosities (Mitchell, Bull & Cleland, 2012). However, no study so far showed that this type of task can effectively elicit a SNARC-like effect for the size of pictorial surfaces. To our knowledge, the only study that showed a SNARC-like effect in this specific domain used a comparison task in which the size of target figures was directly compared with the size of reference figures (Ren et al., 2011, Experiment 2).

In order to further investigate whether the size of illusory figures elicit a SNARC-like effect similarly to the size of pictorial figures with physical contours, we run experiment 4 by using the same stimuli as Experiment 3 but employing a different type of task. Similarly to Ren et al. (2011), the task required the direct comparison of the size of target and reference figures.

5. EXPERIMENT 4

Experiment 4 was designed to replicate the Experiment 3 by using a direct comparison task. Therefore, participants were requested to compare the size of target and reference figures both for illusory and real triangles. As for the previous experiment, we hypothesized that if the phenomenal size of the illusory triangle elicits a SNARC-like effect, the same effect should be present for both illusory and real triangles (phenomenal magnitude hypothesis). Conversely, if a SNARC-like effect is elicited exclusively by the size of pictorial figures with physical contours, this effect should be revealed only for real triangles but not for illusory triangles (physical magnitude hypothesis).

5.1 Method

5.1.1 Participants. Twenty-one participants took part in Experiment 3. Twenty were right-handed and one left-handed; all of them were used to the left-to-right writing direction. They had a mean age of 24.8 (*SD* = 2.6). Sixteen of the participants were female and five were male. All participants had normal or corrected-to-normal vision and were naive about the purpose of the experiment and the hypothesis being tested. Participants were all volunteer psychology students from the University of Trieste. Informed consent was obtained prior to participation in the experiment, which was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

5.1.2 Apparatus and stimuli. Apparatus and stimuli were the same as in Experiment 3. The only difference was that we created two reference stimuli (one illusory triangle and one real triangle) that had a medium size in comparison to the four target figures used in the previous experiment. Specifically, the distance between the inducers'disks of both figures was 5.75 deg of visual angle. These two figures were the middle reference standards used to compare the size of the target figures, which were the same as in Experiment 3.

5.1.3 Procedure. The experimental setting and the participants' position were the same as in the previous experiments.

After the fixation cross, the reference stimulus was presented in the center of the screen for 1500 ms, followed by a blank screen for 1000 ms and the target stimulus that lasted till participants responded or for a maximum of 2000 ms. The task consisted in judging whether the target figure was smaller or larger that the reference one by pressing one of two response keys. Illusory and real triangles were tested in two separate blocks. The order of the two blocks was counterbalanced across participants and participants had a five minutes break between them.

Each block was then divided into two sessions. In the first one, participants were asked to press the leftmost key, with their left hand, when the target triangle was smaller than the reference one and the rightmost key, with their right hand, when the target triangle was larger than the reference one. In the second session, the assignment was reversed. The order of the two sessions was counterbalanced across participants. The rest of the procedure was the same as in Experiment 3.

5.1.4 Experimental design. We employed a 2x2x2x4 within subjects factorial design as in the previous experiment.

5.2 Data analysis and results

Errors (2.1%) were removed from the analysis as well as outlier RTs below 150 ms and above 1000 ms (2.3%).

A repeated-measures ANOVA was run for mean response times (RTs). The results revealed a significant main effect of Condition Block [$F(1,20) = 6.17$; $p < .05$; $\eta^2 = .24$], Response Location [$F(1,20) = 9.51$; $p < .01$; $\eta^2 = .32$] and Inducers' Distance [$F(3,60) = 27.19$; $p < .001$; $\eta^2 = .58$]. Conversely, the main effects of Orientation [$F(1,20) = 1.89$; $p = .18$] was non-significant. The interaction between Inducers Distance x Response Location [$F(3,60) = 9.64$; $p < .001$; $\eta^2 = .33$] was significant, suggesting the presence of a SNARC-like effect. Conversely, the interaction between Inducers Distance x Response Location x Condition Block [$F(3,60) = 0.44$; $p = .72$] was non-significant, as well as all the other interactions. The lack of a significant interaction between Inducers Distance x Response Location x Condition Block suggests that the SNARC-like effect, revealed by the Inducers Distance x Response Location interaction, was not moderated by the condition.

As for experiments 2 and 3, a regression analysis of repeated measures was also conducted. Separate analyses were performed for the illusory and real triangles. The analysis of dRTs revealed that the regression slopes of both illusory [$t(20) = -2.47$; $p < .05$] and real [$t(20) = -2.56$; $p < .05$] triangles were significantly different from zero, suggesting the occurrence of a SNARC-like effect in both condition blocks. Furthermore, a paired sample t-test performed on the beta regression weights of both illusory and real triangles indicates that the two conditions do not differ significantly [$t(20) = -0.54$; $p = .60$] (Figure 7). The results of the regression analysis, thus, confirm those of the ANOVA, suggesting that a SNARC-like effect was elicited by the size of both illusory and real triangles during a direct comparison task.

Fig. 7 Mean differences of the median RTs right hand – RTs left hand as a function of inducers' distance in Experiment 4. Red diamonds represent the triangle condition, while black disks represent the control condition. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean.

5.3 Discussion

The aim of Experiment 4 was control for the role of the task. The same settings of experiment 3 was adopted but the direct comparison task was used. Participants were required to compare the size of the same target figures of Experiment 3 with that one of a middle reference standard. The results of both ANOVA and regression analysis suggested that a SNARC-like effect is elicited by the size of both illusory and real triangles during a comparison task. Indeed, with both type of stimuli, left responses were faster for small triangles, while right responses were faster for large triangles. The shape of this association resembles a categorical rather than a linear effect, as predicted for the SNARC effect in a direct comparison task (Wood et al., 2008).

6. GENERAL DISCUSSION

In this study, we investigated whether the phenomenal size of visual illusions elicits a SNARC-like compatibility effect similar to those elicited by the physical size of pictorial surfaces. In this was it was possible to disentangle between the physical and phenomenal magnitude hypotheses: the first asserting that…. The second stating that… We ran four experiments, employing the Delboeuf size-contrast illusion (Experiment 1) and the Kanizsa triangle illusion (Experiments 2, 3 and 4). While the first three experiments failed to clearly disentangle between the physical and phenomenal magnitude hypotheses, the results of Experiment 4 suggest that the phenomenal size of visual illusions does elicit a SNARC-like compatibility effect similarly to the size of pictorial figures with physical contours, during a direct comparison task (Exp. 4). Thus, the evidence of the last experiment supports the phenomenal magnitude hypothesis (the phenomenal size of visual illusions elicits a SNARC-like compatibility effect similarly to the physical size of pictorial surfaces) against the physical magnitude hypothesis (only the physical size of real figures elicits a SNARC-like compatibility effect).

In Experiment 1, participants were required to compare the phenomenal size of two equally sized target disks surrounded by two different size *annuli* (Delboeuf size-contrast illusion). Response latencies results do not support the hypothesis that the phenomenal size of the targets elicits a SNARC-like effect (phenomenal magnitude hypothesis). Indeed, participants showed a reversed response pattern; namely they were faster in responding when smaller target appeared to the right and the larger target to the left. This suggests that the spatial compatibility effect is due to the physical size of the inducers rather than to the phenomenal size of the targets (physical magnitude hypothesis). This evidence, however, does not allow us to reject the phenomenal magnitude hypothesis since a SNARC-like compatibility effect might exist both for the phenomenal size of the targets and the physical size of the inducers. Our results simply suggest that when phenomenal and physical magnitudes are opposed, the physical magnitude prevails. This should not be surprising here since the difference in size between the inducers is much bigger than the difference for the phenomenal size of the targets. Therefore, if a SNARC-like compatibility effect exists for the phenomenal size of the targets, this would be masked by a stronger and opposite effect of the physical size of the inducers. Since the Delboeuf size-contrast display does not allow to disentangle between the two hypotheses, we used the Kaniza's triangle illusion in the succesive experiments.

In Experiment 2, participants were required to judge the orientation of the inducers in two displays, a Kanizsa triangle illusion and a Non-Kanizsa control figure. Our results suggest that the phenomenal size of the illusory triangles do not elicit a SNARC-like effect. Conversely, a significant SNARC-like effect was revealed in the control condition by the regression analysis, but not by the ANOVA. The result of Experiment 2, although anomalous at a glance, might suggest that the two conditions are perceived in a very different way in spite of the small difference in the physical display. Indeed, we should reflect on the different perceptual outcome elicited by the two displays. In the illusory triangle condition, the most salient aspect in the display was the illusory triangle, while the distance between the inducers becomes poorly salient. Conversely, in the control condition, the distance between the inducers was the only salient information of the display and this may have caused the SNARC-like effect. Indeed, it seems that the illusory triangles mask the magnitude information (distance) provided by the inducers, which becomes relevant only in the control condition. The effect revealed in the control condition might also have been generated by the task instructions that explicitly focused on the orientation of the inducers and did not refer to the presence of a triangle. However this puzzling outcome should be cautiously interpreted. Although we proposed a speculative hypothesis to account for the results of the regression analysis, the lack of a significant interaction between inducers' distance and response location in the ANOVA suggests that a consistent SNARC-like effect is missing in both conditions.

In Experiment 3, our goal was to further investigate the occurrence of a SNARC-like effect for the phenomenal size of visual illusions by running a modified version of Experiment 2, in which real triangles with physical contours were presented instead of Non-Kanizsa control figures. It is noteworthy that the control figures in Experiment 2 matched the illusory triangles from a physical point of view but elicited a different perceptual outcome, conversely, the control figures used in Experiment 3 were physically different from the illusory triangles, but their perceptual outcome was quite similar. Furthermore, using real triangles as control figures allowed us to modify the task instructions by pointing the focus directly on the triangles instead of on the inducers. Regardless of the instructional manipulation, a SNARC-like effect for the phenomenal size of the illusory triangle was still missing, replicating the findings of the previous experiment. Similarly, no evidence of a SNARC-like effect for real triangles was revealed, suggesting that the size of both real and illusory triangles does not elicit a SNARC-like effect during an orientation judgment task. Although this type of task showed to be effective in eliciting a SNARC effect with some kinds of stimuli (Fias et al., 2001; Prpic et al., 2016; Mitchell et al., 2012), there is no evidence that the size of pictorial surfaces elicits a SNARC-like effect, which was only found with a direct comparison task (Ren et al., 2011).

In Experiment 4, we tested the same stimuli used in Experiment 3 by employing a direct comparison task. Participants were required to compare the size of target figures with the one of a middle reference standard. Both ANOVA and regression analyses consistently indicated that a significant SNARC-like effect was elicited for both types of figures, with faster left-keypress responses for triangles being smaller than the reference, and faster right-keypress responses for triangles being larger than the reference. The analyses also indicate that the SNARC-like effect in the two conditions did not differ significantly. These results successfully replicate the study by Ren et al. (2011), showing that the size of pictorial figures elicit a SNARC-like effect, and extend this finding also to the phenomenal size of visual illusions. In particular, the phenomenal size of illusory figures without physical contours, such as the Kanizsa triangle illusion (1955), showed to elicit a SNARC-like effect analogous to that of real triangles with physical contours. This evidence supports the phenomenal magnitude hypothesis against the physical magnitude hypothesis.

The findings of Experiment 4 can help to shed light on the results of previous experiments. Indeed, these further suggest that the phenomenal size of target disks in Experiment 1 may have been masked by a stronger and opposite effect of the physical size of the inducers. As previously stated, the Delboeuf display did not allow to further disentangle between the effect of the inducers' and targets' size, since these cannot be manipulated separately.

Converging evidence from Experiment 2 and 3 suggests that an orientation judgment task does not elicit a SNARC-like effect for the size of pictorial surfaces, regardless of the nature of the figures being used (either physical or illusory). A recent systematic review and meta-analysis on SNARC–like effect in non-numerical domains may help in interpreting our outcome (Macnamara, Keage & Loetscher, 2018). The authors showed a significant effect size advantage for tasks using explicit comparative instructions, such as the direct comparison task used in our Experiment 4 and in Ren et al. (2011), compared with indirect tasks, such as the orientation judgment used in Experiment 2 and 3. This suggests that the spatial association effect is stronger and more consistent with explicit comparative instructions, while indirect tasks show smaller effects or even fail to elicit them. Indeed, there are several examples in the non-numerical domain that showed a significant effect with direct comparison tasks but not with indirect tasks (Lidji et al., 2007; Prpic, Fumarola, De Tommaso, Baldassi & Agostini, 2013; Rusconi, Kwan, Giordano, Umilta & Butterworth, 2006).To our knowledge, the opposite has never been reported in the literature.

One explanation for this difference is that direct comparison tasks require to explicitly process the magnitude associated with the stimuli, consequently eliciting a stronger association between magnitude and response location than tasks where the magnitude is irrelevant. Another explanation for the different outcome of direct comparison and indirect tasks is the "instruction homogeneity". On the one hand, direct comparison tasks use highly homogeneous instructions, indeed they all require to categorize one of two stimuli as being smaller/larger, slower/faster, shorter/longer than the other. On the other hand, indirect tasks use heterogeneous instructions, indeed they may require processing highly dissimilar features of the stimuli (e.g., color, shape and orientation in Fias et al., 2001; line continuity in Fumarola et al., 2016; timbre sound in Lidji et al., 2007; Prpic et al., 2013; Prpic & Domijan, in press; Rusconi et al., 2006). It is noteworthy that not all feature of the stimuli might be equally efficient in eliciting SNARC-like effects (Fias et al., 2001). In this regards, the authors suggest that this efficiency might depend on the degree of neural overlap of structures that are dedicated to the processing of relevant and irrelevant stimuli information. Therefore, although an indirect task (i.e., parity judgment) became a standard for investigating the SNARC effect for numerical stimuli (Dehaene et al., 1993; Wood et al., 2008), other indirect tasks showed not to be equally efficient with non-numerical magnitudes.

Another relevant point highlighted by Macnamara et al. (2018) pertains the comparison of numerical vs non-numerical magnitudes.After comparing the overall effect size in different studies, they found that the spatial association for the numbers is considerably stronger than for the non-numerical associations. This further suggests that an orientation judgment was probably not the most suitable task for investigating a SNARC-like effect for the size of pictorial surfaces. Future studies investigating SNARC-like effects for the size of pictorial surfaces should focus firstly on direct comparison tasks to assess the existence of an association.

As regards the influence of visual illusions on motor actions, our results suggest that the size of both illusory and real figures interferes with action programming of simple button press movements in a similar fashion. Thus, we did not find evidence supporting a dissociation between motor responses to illusory and real figures. While the majority of studies investigated the influence of visual illusions on motor actions focusing on grasping (for a review see Smeets & Brenner, 2006), we addressed this issue by using a SNARC-like compatibility task. Analogously, while previous studies investigating SNARC-like effects for non-numerical magnitudes focused on the physical properties of the stimuli (e.g., Ren et al., 2011), we focused on their phenomenal properties. In sum, this study represents a first attempt to combine the research on visual illusions and on the SNARC-like effect,. Based on our data, we cannot exclude that the similarity of the outcome for phenomenal and physical magnitudes was due to the strength of the Kanizsa triangle.Future studies may ascertain whether the strength of illusory figures moderates the size of the SNARC-like compatibility effect.

Conclusions

In summary, our findings suggest that phenomenal magnitudes are spatially coded similarly to physical magnitudes. This was revealed when participants were required to directly compare the phenomenal size of Kanizsa triangle illusions, showing faster left (vs. right) responses for small (vs. large) illusory triangles. Real triangles with physical contours also showed the same pattern and our analyses suggest that the effect for these two types of stimuli did not differ significantly.A similar effect was not revealed in an orientation judgment task, suggesting that the size of pictorial surfaces interacts with the space of response execution only in tasks requiring to directly compare the size of the stimuli. Our results support previous research showing that non-numerical magnitudes, such as the physical size of pictorial surfaces, elicit SNARC-like compatibility effects and extends those findings to the domain of visual illusions.

Ethical standards

The present study was approved by the ResearchEthics Committee of the University of Trieste in compliance withnational legislation, the Ethical Code of the Italian Association ofPsychology, and the ethical standards laid down in the 1964 Declarationof Helsinki and its later amendments.

Conflicts of Interest

The authors declare no conflict of interest.

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