Acta Psychologica 156 (2015) 179–191

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Can conceptual congruency effects between number, time, and space be accounted for by polarity correspondence?

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ARTICLE INFO

Available online 24 December 2014

PsycINFO code:
2340

Keywords:
Conceptual metaphor
Polarity correspondence
Space
Time
Number
Conceptual congruency

ABSTRACT

Conceptual congruency effects have been interpreted as evidence for the idea that the representations of abstract conceptual dimensions (e.g., power, affective valence, time, number, importance) rest on more concrete dimensions (e.g., space, brightness, weight). However, an alternative theoretical explanation based on the notion of polarity correspondence has recently received empirical support in the domains of valence and morality, which are related to vertical space (e.g., good things are up). In the present study we provide empirical arguments against the applicability of the polarity correspondence account to congruency effects in two conceptual domains related to lateral space: number and time. Following earlier research, we varied the polarity of the response dimension (left-right) by manipulating keyboard eccentricity. In a first experiment we successfully replicated the congruency effect between vertical and lateral space and its interaction with response eccentricity. We then examined whether this modulation of a concrete-concrete congruency effect can be extended to two types of concrete-abstract effects, those between left-right space and number (in both parity and magnitude judgment tasks), and temporal reference. In all three tasks response eccentricity failed to modulate the congruency effects. We conclude that polarity correspondence does not provide an adequate explanation of conceptual congruency effects in the domains of number and time.

1. Introduction

Recent years have witnessed a strong interest in the possibility that the mental representation of abstract concepts relies in a deep sense on more concrete concepts (Dehaene, 1997; Lakoff and Johnson, 1999; Mandler, 1992; Walsh, 2003). Under this view, an abstract conceptual domain imports structure and content from a better understood, more clearly delineated, more concrete conceptual domain. For example, time is understood as physical motion from one location to another, either along the front-back axis (Boroditsky, 2000) or the left-right axis (Santiago et al., 2007). Other examples include power and size (Sorokowski, 2010), affective evaluation and vertical location (Crawford et al., 2006) or brightness (Meier, Meier et al., 2004), gender stereotypes and toughness (Slepian et al., 2011) and numerical magnitude and the left-right axis (Dehaene et al., 1993). Such a view suggests that the mental representation of concepts is hierarchically structured, such that more concrete concepts are more directly linked to perceptual-motor experiences, and these in turn are used to support the understanding of more abstract levels (Lakoff and Johnson, 1999). According to this theoretical viewpoint, the whole human conceptual structure is anchored to, or grounded in our embodied interaction with the external world (see Lakens, 2014; Santiago et al., 2011).

An important source of evidence for such a view comes from conceptual congruency tasks. In these tasks, bi-polar endpoints of a concrete and an abstract dimension are factorially crossed. Participants' main task requires the processing of the abstract dimension (e.g., by categorizing words on their meaning), and the effects of the concrete, task-irrelevant dimension (e.g., their spatial position on the screen) are measured. When task-irrelevant cues interact with semantic categorization judgments, the congruency effect is often interpreted as support for the idea that people use concrete representations to mentally scaffold abstract judgments. A well-known example is the Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene et al., 1993). In a typical SNARC task, the participant has to make a numerical categorization, such as deciding whether a number is odd or even (a "parity task"), by means of left or right key presses. The response location (left or right) is the task-irrelevant concrete dimension. The standard result, now widely replicated, consists in faster categorizations when responding to a small number with the left hand and to a large number with the right hand versus using the reverse mapping (for reviews, see Gevers

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http://dx.doi.org/10.1016/j.actpsy.2014.09.016
0001-6918/

and Lammertyn, 2005; Wood et al., 2008). Analogous findings have been observed for temporal concepts, with better performance when past is mapped to left and future to right space (for a review, see Bonato et al., 2012). These congruency effects are often interpreted as evidence for the use of a spatial left-right line to mentally represent the abstract concepts of number magnitude and time.

1.1. Polarity correspondence

Interpreting congruency effects as evidence for how people mentally represent concepts has not been free from criticism, both on theoretical (e.g., Dove, 2009; Kranjec and Chatterjee, 2010; Machery, 2009; Mahon and Caramazza, 2008; Paivio, 1986) and empirical grounds (e.g., Eder and Rothermund, 2008; Hutchinson and Louwerse, 2014; Kemmerer, 2005; Santens and Gevers, 2008). One recent alternative account for conceptual congruency effects is based on the concept of markedness and the principle of polarity correspondence (Proctor and Cho, 2006; see Lakens, 2011; Louwerse, 2011; Van Dantzig and Pecher, 2011). According to the polarity correspondence view, concrete representations of any kind may not be needed to account for many of the published conceptual congruency effects: mappings between two bi-polar dimensions can emerge based on purely structural features.

The concept of markedness has a long tradition in linguistics (Greenberg, 1963) and psycholinguistics (Clark, 1969). The two poles of most conceptual dimensions (e.g., happiness or tallness) do not seem to enjoy the same representational status. One endpoint, which we will refer to as the $+$*pole*, is used to refer to the whole dimension (e.g., tall, happy), whereas the other, the $-$*pole*, is used to refer only to itself (e.g., sad, shot). For example, compare the sentence "how tall is John?" versus "how short is John?". Whereas the first question does not presuppose that John's height is in any specific range, the second question implies that John is short. The $+$*pole* is more frequent in language and enjoys a processing advantage compared to the $-$*pole* (Clark, 1969). Proctor and Cho (2006), drawing on ideas first put forward by Seymour (1974), proposed that when two or more dimensions are crossed in a reaction time task, the final pattern of latencies can be predicted from the degree of correspondence between the polarity of the dimensions. When applied to the case of two bi-polar dimensions, this *polarity correspondence principle* predicts that there will be a processing advantage in those conditions where the two polar signs match. Because both the marked polarity of dimensions as well as the principle of polarity correspondence are purely structural features of the mental representation of conceptual dimensions, a polarity correspondence account of conceptual congruency effects does not require the postulation of concrete mental representations (Lakens, 2012).

Proctor and Cho (2006) review many different literatures where the polarity correspondence principle applies or could apply, including stimulus-response compatibility tasks, picture-sentence matching tasks, and orthogonal Simon tasks. The latter are central to the rationale of the present experiment series, so we will describe them in some detail. In a typical orthogonal Simon task, participants are presented with a stimulus in one of two vertical locations (e.g., above or below a fixation point) and are asked to discriminate the location of the stimulus by means of a left or right key-press or a leftward or rightward response with a joystick.[2] The basic finding is that people respond faster when the upper location is mapped onto the right response (and down locations are mapped onto left responses), compared to an up-left down-right mapping (see Proctor and Cho, 2006, for an overview). Following Weeks and Proctor (1990), Proctor and Cho (2006) proposed that the up-right advantage is due to the polarity correspondence principle, because up and right are the $+$*poles* of the vertical and lateral spatial dimensions.

One central characteristic of the polarity correspondence account is that polarities are flexible and can be changed by manipulating the salience or attention paid to each endpoint. This makes it possible to manipulate polarity benefits experimentally. One way to do it is varying response eccentricity, that is, the lateral displacement of the response device. Response eccentricity has been shown to modulate the observed up-right advantage in orthogonal Simon tasks. When the response box, keyboard, or joystick is placed to the right of the screen, the up-right advantage grows stronger. When the response set is located in left space, an up-left advantage is observed instead (Proctor and Cho, 2003). Proctor and Cho (2003); see also Cho and Proctor, 2003; Proctor and Cho, 2006; Weeks et al., 1995) suggested that response eccentricity changes the saliency of the right and left poles of the lateral spatial dimension, effectively turning the left pole into the $+$*pole* when the responses are placed on left space and thus generating the up-left advantage through polarity correspondence. This reasoning is in line with data that show that the endpoint taking $+$*polar* value depends on context (e.g., Banks et al., 1975).

1.2. Applying polarity correspondence to concrete–abstract congruency

The orthogonal Simon effect arises when two concrete (spatial) dimensions are crossed, but the hypothesis of polarity correspondence can be straightforwardly generalized to situations where one concrete and one abstract dimension are crossed. Lakens (2012) adopted this perspective to examine conceptual congruency effects between vertical locations (up vs. down) and the abstract dimensions of power and valence. He reasoned that the conceptual metaphor account predicts a cross-over interaction without main effects, whereas the polarity correspondence account predicts main effects of each dimension (due to the processing advantage of the $+$*pole*) as well as an interaction due to polarity correspondence. When both main effects and their interaction are put together, the polarity correspondence account predicts that moral or positive words will be categorized faster when presented in upper versus lower space, but categorization times for immoral or negative words will be overall slower and will not depend on the spatial position of the stimulus. A meta-analysis of prior studies supported this prediction. Lynott and Coventry (2014) have similarly found the pattern predicted by the polarity correspondence account using happy and sad faces presented up or down on the screen (see also de la Vega et al., 2013).

Polarity correspondence therefore stands as an important theoretical contender in conceptual congruency studies. The importance to differentiate between polarity correspondence and conceptual metaphor accounts has been discussed repeatedly (e.g., de la Vega et al., 2013; Gozli et al., 2013; Schubert, 2005; Ulrich and Maienborn, 2010; Vallesi et al., 2008. However, discriminating between the two alternatives is more difficult than it seems.

1.3. The problem of the interpretation of main effects

The main difficulty is related to the interpretation of the main effects of the dimensions that are crossed in the congruency task. The crucial point is that the conceptual metaphor account does not predict null main effects, but it is instead *silent* about them. Its main prediction is the interaction between the two dimensions, but many other factors may produce main effects for independent reasons. For example, when participants judge the affective valence of positive and negative words, the two conditions may differ in length, frequency of use, bigram or syllable frequency, morphological complexity, and a myriad other factors which are known to affect reading and lexical access. Perceiving upper versus lower stimuli may be affected by extended practice with scanning written texts from top to bottom or the way the task is framed (e.g., Banks et al., 1975). In general, main effects of any concrete or

[2] Typical orthogonal Simon tasks differ from standard Simon tasks in that the vertical location of the stimulus is task relevant, as the participant is instructed to respond to it. In contrast, in a standard Simon task, lateral location of the stimulus is task irrelevant, as the participant is asked to classify other stimulus dimension (often colour).

abstract dimension in a congruency task can be due to factors other than the +*polar* or -*polar* values of its endpoints, and only a delicate experimental control can exclude all of them. For this reason, some researchers have proposed to statistically remove main effects from their analysis, and interpret residual scores (e.g., Meier et al., 2007). If the conceptual metaphor account is not incompatible with main effects of the crossed dimensions, then its predictions become indistinguishable from those drawn from the polarity correspondence account.

Moreover, the same argument applies, though in reverse form, to the predictions of the polarity correspondence account. Polarity correspondence does predict main effects of both dimensions, such that the +*polar* endpoint should enjoy a processing advantage. However, unless strict controls are taken when selecting the stimuli and designing the task, other factors of the kind discussed above may influence the overall reaction times, with additive effects. Sometimes these factors will add to the +*polar* advantage, thereby increasing the size of the difference, but it is also conceivable that they may counteract it, perhaps reducing it to a non-significant difference or even turning it into an effect in the opposite direction.

Therefore, unless strict controls are in place that guarantee all reaction time benefits are of equal strength, main effects cannot be used to discriminate between the conceptual metaphor and polarity correspondence accounts. Only the interaction (the congruency effect) remains. Whereas both accounts predict its presence, fortunately, they make different predictions regarding how it may be influenced by experimental manipulations. Under the polarity correspondence view, polarities can be changed flexibly, and a change in polarity should lead to a reversal of the congruency effect. This is nicely illustrated by the effects of keyboard eccentricity on the orthogonal Simon effect reviewed above: increasing the saliency of the left side by placing the keyboard to the left reverses the standard up-right advantage into a left-right advantage (e.g., Proctor and Cho, 2003).

Such reversal is not predicted by the conceptual metaphor view. Under this view, cross-domain mappings have experiential bases where the concrete dimension is associated to the abstract dimension. For example, Schubert (2005) suggests that the link between vertical space and power comes about because of experiences with bigger (and smaller) others, and/or repeated experiences with cultural conventions such as placing winners on the top of a podium. However, in this account an increase of the saliency of lower space by an experimental manipulation is not expected to lead to a powerful-down advantage in a congruency task (although it might speed up the processing of words presented at lower locations, thereby changing the main effect of vertical location).

The only attempt so far to directly test this prediction is the final experiment in Lakens (2012). He manipulated the polarity of the abstract dimensions by changing the relative frequency of positive-negative and moral-immoral words in a first block of trials where all words were presented in the centre of the screen. In the critical condition, −*polar* words were presented in 75% of the trials, and +*polar* words were presented in 25% of the trials. In the control condition, +*polar* words were presented 75% of the time. After such block, participants carried out a conceptual congruency task with the same words presented at the top or bottom of the screen. Supporting the polarity correspondence account, the frequency manipulation succeeded in changing the congruency effect: whereas there was a clear congruency effect in the 75% +*polar* condition, it disappeared in the 75% −*polar* condition. Unfortunately, available evidence is very limited, and the frequency manipulation used by Lakens (2012) was not able to completely reverse the conceptual congruency effect. The present study tried to bring additional evidence to bear on this debate.

1.4. Rationale of the present research

The current studies examined the central theoretical prediction of the polarity correspondence account, namely that it is possible to reverse a congruency effect by changing the saliency of the endpoints of one of the crossed dimensions (the suggested underlying mechanism being a change in the polarity of those endpoints). In order to do so, we capitalized on the effect of keyboard eccentricity that so impressively is able to reverse the usual up-right advantage observed in orthogonal Simon tasks (Cho and Proctor, 2003; Proctor and Cho, 2003; Weeks et al., 1995). Placing the keyboard to the left side increases the saliency of the left pole of the lateral spatial dimension, and thereby induces a left-right advantage. The goal of Experiment 1 was to replicate this effect.

To assess the effect of keyboard eccentricity on a conceptual congruency task, we needed to substitute an abstract dimension for the vertical spatial dimension in the orthogonal Simon task. In order to have predictions from the conceptual metaphor account, we needed to focus on a dimension which has been linked to the left-right spatial axis (instead of the vertical axis as used by Lakens, 2012). One such dimension is numerical magnitude: in left-to-right readers, smaller numbers are associated with left space and larger numbers are associated with right space (Dehaene et al., 1993). Proctor and Cho (2006) explicitly suggested that polarity correspondence might explain the standard SNARC effect that is obtained in parity judgments. Parity tasks show markedness effects: responding “odd” is slower than responding “even” (especially in contexts that foster a comparison between odd and even numbers, see Hines, 1990). Moreover, responding “odd” with the left hand and “even” with the right hand is faster than vice versa (Nuerk et al., 2004, who called it the Markedness Association of Response Codes, or MARC effect). Proctor and Cho (2006) suggested that large numbers would be +*polar* and small numbers -*polar* and the SNARC effect could arise from polarity correspondence with the +*polar* right response and the -*polar* left response. Based on these predictions, Experiment 2 was performed to examine whether a keyboard eccentricity manipulation would influence the SNARC effect in a parity judgment task on Arabic digits.

In parity tasks the abstract dimension of numerical magnitude is actually irrelevant to the task. In this way, a parity judgment is not exactly analogous to the orthogonal Simon task, in which the vertical spatial location determines the correct response. A better comparison is provided by a magnitude comparison task where participants are instructed to decide whether a digit is smaller or larger than 5, because the task relevant feature (numerical magnitude) is directly associated with left vs. right spatial locations. SNARC effects have been found in magnitude judgments (see, e.g., Wood et al., 2008), and several studies have interpreted them as support for the polarity correspondence hypothesis (Hutchinson and Louwerse, 2014; Nathan et al., 2009; Santens and Gevers, 2008; Shaki et al., 2012). Moreover, categorizing stimuli as large vs. small have revealed stable polarity effects in past studies (e.g., Seymour, 1971). We therefore relied on a magnitude judgment task to examine the influence of response eccentricity on the SNARC effect in Experiment 3.

In addition to the left-to-right mapping of numbers, a second conceptual dimension that is consistently mapped onto lateral space is the domain of time. For left-to-right readers, the past is associated with left space while the future is associated with right space (Fuhrman and Boroditsky, 2010; Lakens, 2011; Ouellet et al., 2010; Tversky et al., 1991). Polarity correspondence has also been discussed as a possible alternative explanation for mappings between space and time (e.g., Santiago et al., 2010; Ulrich and Maienborn, 2010; Weger and Pratt, 2008). Although those mappings have received support from studies which cannot be accounted for by polarity correspondence, Bonato et al. (2012) conceded that “it can provide a parsimonious explanation of the results for some specific studies, in which no counter-solutions to this potential confound have been implemented” (p. 2266). Therefore, in Experiment 4 we examined the effect of response eccentricity on categorization times for past and future related words, categorized by means of left or right key presses.

Summing up, if the left-right numerical and/or temporal congruency effects are, in all or in part, due to polarity correspondence, then manipulating the eccentricity of the response location should change the congruency effect in the response time data. The polarity correspondence account predicts standard congruency effects when the response set is either central or to the right. Crucially, it predicts a reduced or inverted effect when the response set is located on the left side. Under this condition, the left response becomes more salient, and therefore the polarity correspondence reaction time benefit should be observed between larger numbers or future words and the left response, and between smaller numbers or past times and the right response.

2. Experiment 1

Experiment 1 was a replication of the keyboard eccentricity effect reported by Proctor and Cho (2003) Experiment 1). We followed their procedure in all central details: the stimulus was a square made of crosses presented either above or below the fixation point, and participants' task was to discriminate its location by pressing the right or left key.

2.1. Method

2.1.1. Participants

Participants were 18 psychology students from the University of Granada (all female, 2 left-handers, age range 18-30 y., normal or corrected vision), who received course credit for their participation.

2.1.2. Materials and procedure

The target stimulus was an array of 3x3 asterisks that looked like a rectangle. The target was presented horizontally centred midway between fixation and either the upper or lower border of the screen. Instructions informed the participant that his or her task was to press a left (F) or right (J) response key on the keyboard (with the left or right hand, respectively) depending on whether the target appeared above or below the fixation point. Because of the simplicity of the task, there was no practice block. Each trial started with a central fixation cross for 1000 ms, followed by the target stimulus, which stayed on screen until a response was recorded. Incorrect trials were followed by the word "Incorrecto" for 500 ms in red font at fixation location. Finally, a blank screen was presented for an inter-trial interval of 1000 ms.

Experimental trials were divided into six blocks of 56 trials, with 28 presentations of the target stimulus at each location. The mapping of responses (upper-lower) to keys (left-right) was kept constant during three blocks, and then reversed in the following three blocks (following Proctor and Cho, 2003). The order of the two key mappings was counterbalanced between participants. At the beginning of each block, a screen reminded the participant of the mapping to be used. In block number 4, a special warning was added to this screen to emphasize that the mapping was being reversed.

Keyboard location was varied within-participants following Proctor and Cho's (2003) specifications. The central location was defined as that in which the centre of the two response keys was aligned with the centre of the screen. The left and right locations were displaced 30 cm to each side. In one set of three blocks, the keyboard started at the left location in one block, then was moved to the centre in the next block, and then to the right. In the other set of three blocks, the keyboard started at the right location and was moved leftwards. Half the participants performed first the rightwards three blocks followed by the leftwards three blocks, while the other half had the reversed order.

2.1.3. Design and analysis

The design included the following factors and levels: Vertical location (up-down) × Response (left-right) × Keyboard location (left-centre-right) × Counterbalance group. Detailed results, including both cell means and standard errors as well as full ANOVA results, are provided by means of tables. Because the only effects for which we have specific predictions are the two-way interaction between Vertical location and Response (the orthogonal Simon effect) and the three-way interaction between the orthogonal Simon effect and Keyboard location, only these two effects are described in the text. Confidence intervals were calculated following Smithson (2001).

2.2. Results

There were errors in 137 trials (2.26%), which were analyzed independently. After inspection of the RT distribution, cut-off points were set at 250 and 1250 ms, which led to the rejection of 119 (1.85%) outliers. To ensure comparability across studies, in the next experiments we used the same trimming procedure and rejected a similar percentage of data points (this procedure keeps the proportion of outliers constant across experiments, but the cut-offs might vary depending on grand average response speed).

Full results are provided in Tables 1 to 3 in the Appendix. The analysis of latency revealed a very clear interaction between Vertical location and Response ($F(1, 14) = 11.05$, $p = .005$, $\eta_p^2 = .44$, 90% CI [.10, .63]. Unexpectedly, this interaction took the form of an up-left advantage (possible causes are discussed below). However, the crucial aspect of the data is that this interaction was strongly modulated by Keyboard location ($F(2, 28) = 25.73$, $p < .001$, $\eta_p^2 = .65$, 90% CI [.42, .74]; see Fig. 1). The up-left advantage was present when the keyboard was located on the left and on the centre, and turned into a numerical up-right advantage when the keyboard was moved to the right. This pattern complies with expectations from previous findings by Proctor and Cho (2003).

Accuracy data supported the findings of the latency measure. There was an interaction between Vertical location and Response ($F(1,14) = 7.85$, $p = .014$, $\eta_p^2 = .36$, 90% CI [.05, .57]) which was modulated by Keyboard location ($F(2,28) = 9.04$, $p = .001$, $\eta_p^2 = .39$, 90% CI [.13, .54]), due to an up-left advantage at left and central keyboard locations which turned into an up-right advantage when the keyboard was placed on the right side.

2.3. Discussion

In Experiment 1 an up-left advantage was observed both in latency and accuracy when the keyboard was placed at midline as well as on the left, which turned into a (small) up-right advantage when the keyboard sat on the right side. Proctor and Cho (2003) found an up-left advantage with the keyboard on the left, a very small up-right advantage with the keyboard on the centre, and an up-right advantage with the keyboard on the right side. Therefore, we take the present results to constitute a successful replication of their findings: keyboard eccentricity affects the saliency of the side of space where the keyboard lies, and the most salient side of the left-right dimension attracts the mapping of the *+pole* of the vertical dimension (up).

The main contrast between present results and those reported by Proctor and Cho (2003) and others is the finding of an up-left (instead of up-right) advantage when the response set is placed at midline. As a post-hoc speculation, we think that the cause may be related to the spatial arrangement of the experimental equipment with respect to the room at the Granada lab. The computer and keyboard were located on a corner of the lab. When sitting at the computer, the participant had a window on her right and the room extended to her left. This may have made her conceptualize the equipment as being located to the left of the window. Both Weeks et al. (1995) and Proctor and Cho (2003) have shown that instrumental factors that increase the saliency of left or right space is influenced by how the response set is located with respect to relevant frames of reference. For example, placing an unused joystick to the right of the response keyboard was enough to turn the up-right advantage into an up-left advantage. A similar phenomenon may have occurred in the present experiment with the highly salient window located on the right side of the participant.

The important point to note here is that the present orthogonal Simon effect and its interaction with keyboard eccentricity provide an

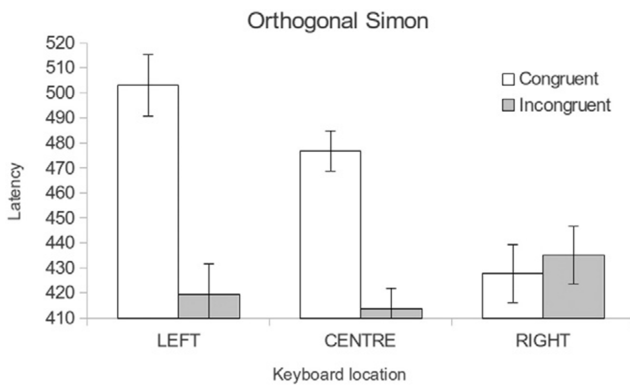

Fig. 1. Mean latencies as a function of keyboard location and vertical-horizontal congruency in an orthogonal Simon task. Congruent conditions are up-right and down-left. Incongruent conditions are up-left and down-right. Error bars show one standard error above and below the mean. Standard errors are adjusted for within-subject designs following the method proposed by Cousineau (2005).

adequate (actually, a specially sensitive) baseline for the upcoming experiments for two reasons. First, the exact same experimental set-up was used in Experiments 2 and 3 (with the same computer, the same keyboard, and the same three keyboard locations, indicated by the same marks on the table). Second, the present experimental setup seems to have endowed the left pole of the left-right response dimension with a strong saliency (generating an up-left advantage not only when the keyboard was placed on the left but also at midline). A highly salient left pole should have an increased ability to attract the *+pole* of the abstract dimension in subsequent experiments, leading to reversed SNARC effects. To advance the results in the following two experiments, we did not find the slightest trace of such reversal.

3. Experiment 2

As opposed to Experiment 1, where stimuli consisted of targets presented above or below a fixation point, the stimuli in Experiment 2 were centrally presented single digits from 1 to 9 (with the exception of 5). Participants judged whether the digit was odd or even (parity judgment) by means of left and right key presses on a keyboard which could be located at either the left, centre, or right of the screen.

3.1. Method

3.1.1. Participants

Twenty psychology students (three male, age range 18-39) from the University of Granada volunteered to participate and received course credit in return. All participants were right-handed and had normal or corrected-to-normal vision.

3.1.2. Materials and procedure

The single digits 1 to 4 and 6 to 9 were centrally presented on the same computer as in Experiment 1. Written instructions informed the participant that a single digit would be presented in each trial, and that his or her task was to decide whether the digit was odd or even. The participant was to respond by pressing the keys F (left) or J (right). All digits were presented once every eight trials.[3] All other details of the procedure were kept the same as in Experiment 1.

3.1.3. Design and analysis

Data were analyzed using a factorial ANOVA with the following factors and levels: Parity (odd-even) × Magnitude (smaller-larger than 5) × Response (left-right) × Keyboard location (left-centre-right) × Counterbalance group. We expected to replicate 1) the SNARC effect (an interaction between Magnitude and Response such that smaller numbers are responded to faster with the left hand and larger numbers with the right hand versus the opposite mapping); and 2) the MARC effect (an interaction between Parity and Response such that odd numbers are responded to faster with the left hand and even numbers with the right hand). But the central prediction to test is the three-way interaction between Magnitude, Response (the SNARC effect), and Keyboard location. If the SNARC effect varies with Keyboard location, such that it decreases in size or even reverses when the keyboard is placed on the left side, the polarity correspondence account of the SNARC effect will receive direct support from the data. Another highly diagnostic result would be a three-way interaction between the MARC effect and Keyboard location.

3.2. Results

Errors occurred in 280 trials (4.32%) and were analyzed independently. Latencies in correct trials were trimmed by means of fixed cut-off points, set at 300 and 1300 ms after inspection of the RT distribution, which led to the rejection of 100 trials (1.54%) as outliers.

Tables 4 to 6 in the Appendix show results in full detail. The analysis of latency showed a very clear pattern. There was an interaction between Magnitude and Response ($F(1,16) = 8.12$, $p = .012$, $\eta_p^2 = .34$, 90% CI [.05, .55]), replicating the SNARC effect. The interaction between Parity and Response (the MARC effect) and any second order interactions between either the SNARC and the MARC effects with Keyboard location were far from significant (all $Fs < 1$). Fig. 2 shows the main results. None of the crucial interactions were significant in the analysis of accuracy.

3.3. Discussion

Experiment 2 showed that keyboard location did not modulate the SNARC effect. This contradicts the predictions from a polarity correspondence account: if the location of the response set modifies the polarity structure of the left-right response dimension, and if the SNARC effect arises as a result of polarity correspondence between numerical magnitude and response, it should be affected by changes in keyboard location. This is even more strongly predicted in the present conditions which were characterized by an extra boost of saliency to the left pole of the response dimension, as suggested by Experiment 1. Moreover, there was neither an interaction between parity and response side (MARC

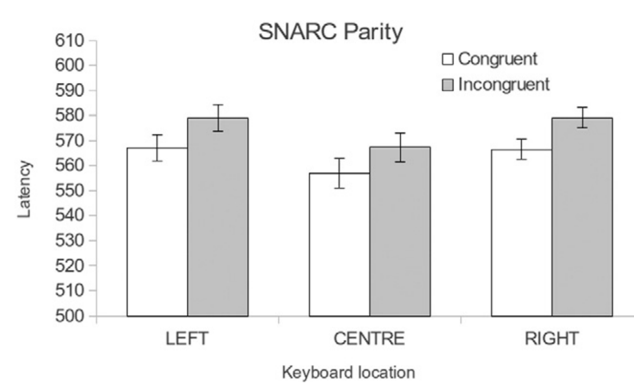

Fig. 2. Mean latencies as a function of keyboard location and space-magnitude congruency in a parity judgment task ("Is the number odd or even?"). Congruent conditions are small-left and large-right. Incongruent conditions are large-left and small-right. Standard error bars computed following Cousineau (2005).

[3] Due to a programming error, there were 54 trials per block (instead of 56) in Experiment 2. Because 54 is not evenly divisible by eight, not all eight digits were presented with equal frequencies within each block, varying between 6 and 8 presentations, modally 7. This problem was of scarce significance thanks to the requirement inbuilt in the program to present all eight digits every eight trials. Over the whole experiment, the frequency with which each digit was presented varied between 34 and 38 trials. This error was solved in Experiment 3, with exactly 7 presentations of each digit per block.

effect) nor a modulation of this interaction at different keyboard locations. Thus, the pattern of results in Experiment 2 does not support the central prediction from the polarity correspondence view. In Experiment 3 we aimed to extend these results to a magnitude judgment task.

4. Experiment 3

In Experiment 2, the concrete dimension of vertical space was changed to the abstract dimension of numerical magnitude. However, the two experiments also differed in the task relevance of the stimulus dimension: whereas participants judged vertical location in Experiment 1, they judged number parity in Experiment 2, instead of the theoretically relevant numerical magnitude. In order to provide a closer comparison, Experiment 3 was an exact replication of the prior experiment with a single difference: participants judged whether the central digit was smaller or larger than 5.

4.1. Method

4.1.1. Participants

Twenty new participants (3 males, 1 left-hander, age range 18-39) from the same population as in Experiment 2 took part in the study and received credit course in return.

4.1.2. Materials and procedure

Everything was kept identical to Experiment 2 with the exception of the instructions: participants were told that they had to press one key if the digit was smaller than 5 and another key if it was larger than 5.

4.1.3. Design and analysis

Data were analyzed using the same factorial ANOVA comprising Parity (odd-even) × Magnitude (smaller-larger than 5) × Response (left-right) × Keyboard location (left-centre-right) × Counterbalance group.

4.2. Results

There were errors in 216 trials (3.32%), so the task was slightly easier than in the prior experiment. Latencies of correct trials were trimmed by fixed cut-off points which were set at the same points as in Experiment 2 (300 and 1300 ms) after inspection of the RT distribution. As a result, 120 trials (1.78%) were rejected as outliers. Errors and latencies were analyzed independently.

Tables 7 to 9 in the Appendix provide full results. Regarding the theoretically relevant contrasts, the analysis of latencies once again rendered a clear pattern. The SNARC effect was replicated (Magnitude × Response interaction: $F(1,16) = 6.55$, $p = .021$, $\eta_p^2 = .29$, 90% CI [.03, .51]), but the MARC effect was not ($F < 1$). Keyboard location did not modulate the SNARC effect at all ($F < 1$; see Fig. 3) nor did it modulate the MARC effect ($F < 1$).

The SNARC effect was marginally significant in accuracy ($F(1,16) = 4.04$, $p = .06$, $\eta_p^2 = .20$, 90% CI [.00, .44]). The accuracy measure also showed a significant MARC effect (Parity × Response: $F(1,16) = 7.32$, $p = .016$, $\eta_p^2 = .31$, 90% CI [.04, .53]). But none of these interactions were modulated by Keyboard location (all $Fs < 1$).

4.3. Discussion

Experiment 3 found a SNARC effect on latency and (marginally) on accuracy. In contrast to the prior experiment, there was also a MARC effect on accuracy. None of those potential polarity correspondence effects were significantly modulated by the location of the keyboard. Thus, Experiments 2 and 3 can be summarized as showing clear SNARC effects without any trace of a modulation by keyboard location.

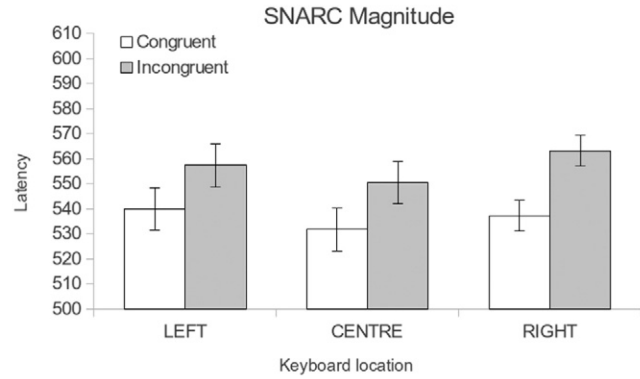

Fig. 3. Mean latencies as a function of keyboard location and space-magnitude congruency in a magnitude judgment task ("Is the number smaller or larger than 5?"). Congruent conditions are small-left and large-right. Incongruent conditions are large-left and small-right. Standard error bars computed following Cousineau (2005).

5. Experiment 4

Experiment 4 extended the previous exploration of the effect of keyboard eccentricity on space-number congruency to the conceptual dimension of time. Participants were asked to categorize words as referring either to the past or the future. Except for the change in stimuli and dimension upon which the stimuli were categorized, the task was identical to that used in Experiment 3. This final study was run at Eindhoven University of Technology in a lab cubicle with a more centrally located computer.

5.1. Method

5.1.1. Participants

Twenty students (9 female, no left-handers, age range 19-33, all with normal or corrected vision) at Eindhoven University of Technology volunteered to participate and received a monetary compensation of 5 euro in return. All of them were native Dutch speakers.

5.1.2. Materials and procedure

The stimulus set consisted of four words referring to the past (eerder [previously], verleden [past], gisteren [yesterday], eergisteren [day before yesterday]) and four words referring to the future (later [later], toekomst [future], morgen [tomorrow], overmorgen [day after tomorrow], see Lakens, 2011). Participants were instructed that a word would be presented at the centre of the screen and that their task was to decide whether the word referred to the past or to the future. Because this experiment was run at a different lab, the computer and room arrangement were different from prior experiments.

5.1.3. Design and analysis

The factorial design included Time (past-future) × Response (left-right) × Keyboard location (left-centre-right) × Counterbalance group.

5.2. Results

The temporal task was somewhat more difficult than the numerical tasks. Errors were made on 292 trials (4.34%) and were analyzed independently. After inspection of the RT distribution, cut-off points were set at 300 and 1800 ms, which removed 108 trials (1.6%). Tables 10-12 in the Appendix show full results.

The analysis of latency showed only one significant interaction: that between Time and Response ($F(1,16) = 7.37$, $p = .015$, $\eta_p^2 = .32$, 90% CI [.04, .53]), which took the expected form of faster responses with the past-left future-right mapping than the opposite mapping. Once again there were no traces of a modulation of the space-time congruency effect by Keyboard location ($F < 1$; see Fig. 4). Latency results were not qualified by the analysis of accuracy, as no main effects nor interactions were found.

5.3. Discussion

Experiment 4 replicated the space-time congruency effect observed in prior studies (e.g., Santiago et al., 2007), which was not modulated by response eccentricity. Predictions from the polarity correspondence account were therefore not supported. These results extend the conclusions from Experiments 2 and 3 to the domain of time.

6. Additional analyses

The present experimental series provided clear results regarding the most important prediction under scrutiny: that spatial-conceptual congruency effects for both number and time would interact with the eccentricity of the response set. We observed significant interactions between response (left vs. right) and numerical magnitude (small vs. large numbers) in Experiments 2 and 3, using two different number processing tasks. Side of response also interacted significantly with temporal reference (past vs. future) in Experiment 4. However, response eccentricity never modulated those interactions. Thus, the main prediction from the polarity correspondence view is not supported.

However, it is possible that the effect of response eccentricity is present in the population, but that our sample sizes were too small to provide sufficient power to observe a statistically significant moderation. In this section we report omnibus ANOVAs in which we pool the data from the present experiments in order to increase the statistical power of the test. Given that all studies had similar numbers of participants, this approach is comparable to a meta-analysis performed on the raw mean differences (Bond et al., 2003). Data from all four experiments were pooled together under the following design: Study × Keyboard location × Congruency × Counterbalance group. Congruency was computed by pooling together the conditions with congruent mapping in each experiment versus the conditions with incongruent mapping. For Experiment 1 the congruent conditions were up-right and down-left. For Experiments 2 and 3 the congruent conditions were left-small and right-large (note that Parity was not included, as there are no corresponding factors in Experiments 1 and 4). For Experiment 4 the congruent conditions were left-past and right-future.[4]+

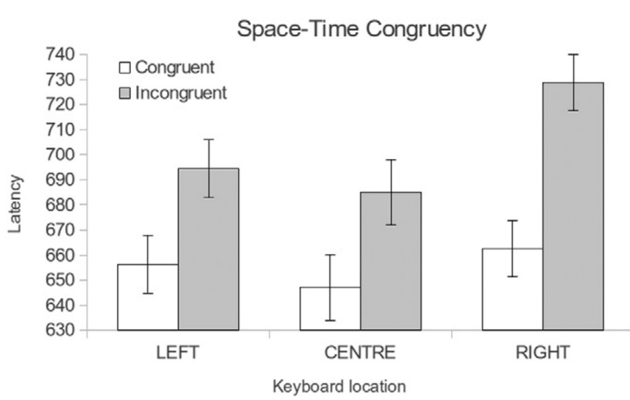

Fig. 4. Mean latencies as a function of keyboard location and space-time congruency in a time judgment task ("Does the word refer to the past or to the future?"). Congruent conditions are past-left and future-right. Incongruent conditions are future-left and past-right. Standard error bars computed following Cousineau (2005).

The rationale for the analysis was as follows: first, we carried out an omnibus ANOVA of Experiments 2 to 4, with the goal of showing that the Congruency effect is strong and, even with the additional statistical power, is not modulated by Keyboard location. Second, we introduced Experiment 1 in the omnibus ANOVA with the goal of examining whether this yields a significant interaction between Study, Keyboard location, and Congruency, which would support the conclusion that the first experiment showed a reaction time pattern in the interaction between Keyboard location and Congruency that is statistically different from the prior three experiments.

The results supported the conclusions drawn from previous analyses. In the latency measure, pooling together Experiments 2 to 4, there were main effects of Study ($F(2,48) = 14.25$, $p < .001$, $\eta_p^2 = .37$, 90% CI [.17, .50]), Keyboard location ($F(2,96) = 5.66$, $p = .005$, $\eta_p^2 = .11$, 90% CI [.02, .19]) and Congruency ($F(1,48) = 16.38$, $p < .001$, $\eta_p^2 = .25$, 90% CI [.09, .40]). The only other result that passed the 0.10 probability level was the interaction between Congruency and Study ($F(2,48) = 2.68$, $p = .08$, $\eta_p^2 = .10$, 90% CI [.00, .18]), due to a stronger congruency effect in the time domain (Experiment 4) than the number domain (Experiments 2 and 3). Most importantly, the interaction between Congruency and Keyboard location was almost non-existent ($F(2,96) = 1.30$, $p = .28$, $\eta_p^2 = .03$, 90% CI [.00, .09]), and did not vary depending on Study ($F < 1$).

When Experiment 1 was included in the analysis, there was a significant three-way interaction between Study, Congruency, and Keyboard location ($F(6,124) = 4.13$, $p < .001$, $\eta_p^2 = .17$, 90% CI [.05, .22]), thereby supporting that the interaction between Congruency and Keyboard location in Experiment 1 took a different shape than in Experiments 2-4. Other significant effects were the main effects of Study ($F(3,62) = 25.09$, $p < .001$, $\eta_p^2 = .55$, 90% CI [.38, .63]) and Keyboard location ($F(2,124) = 3.80$, $p = .03$, $\eta_p^2 = .06$, 90% CI [.00, .12]). The main effect of Congruency in this omnibus analysis failed to be significant ($F(1,62) = 2.00$, $p < .16$, $\eta_p^2 = .03$, 90% CI [.00, .13]), due to the opposite directionalities observed in Experiment 1 versus Experiments 2 to 4. The two-way interaction between Congruency and Keyboard location was significant ($F(2,124) = 10.93$, $p < .001$, $\eta_p^2 = .15$, 90% CI [.06, .24]), but its interpretation is logically dependent on the three-way interaction between Congruency, Keyboard location, and Study mentioned above. Finally, the interaction between Congruency and Study was again significant ($F(3,62) = 10.35$, $p < 0.001$, $\eta_p^2 = .33$, 90% CI [.15, .44]), due to the different size of congruency effects across experiments (including the reversal of the effect in Experiment 1).

The analysis of accuracy supported the latency findings. With Experiment 1 excluded from the analysis, the only significant result was the main effect of Congruency ($F(1,48) = 7.09$, $p = .01$, $\eta_p^2 = .13$, 90% CI [.02, .27]). The only interaction below the 0.10 probability level was between Keyboard location and Study ($F(4,96) = 2.21$, $p = .07$, $\eta_p^2 = .08$, 90% CI [.00, .15]). The theoretically relevant interaction between Congruency and Keyboard location was not statistically significant ($F(2,96) = 1.66$, $p = .19$, $\eta_p^2 = .03$, 90% CI [.00, .10]). When Experiment 1 was included in the analysis, the interaction between Study, Congruency, and Keyboard location became significant ($F(6,124) = 3.67$, $p = .002$, $\eta_p^2 = .15$, 90% CI [.02, .18]). There was also a significant interaction between Study and Congruency ($F(3,62) = 5.44$, $p < .01$, $\eta_p^2 = .21$, 90% CI

[4] For the sake of simplicity, we present an analysis where we collapse across congruent conditions. Such an analysis can hide differences between congruent conditions (see Lakens, 2012). Therefore, we initially analyzed all studies with the factors Response (left vs. right) and Stimulus Polarity (even, large, future, vs. odd, small, past) instead of Congruency. This analysis did not yield any additional insights. Although it did not require the a priori grouping of the left-up/right-down conditions as a congruent mapping, the 3-way interaction presented in the current analysis was mirrored in a 4-way interaction between Study, Keyboard location, Stimulus Polarity and Response ($F(6,124) = 4.13$, $p < .001$, $\eta_p^2 = .17$) with the exact same interpretation.

[.00, .18]) due to the different sizes (and reversal) of the effect of Congruency across studies.

Summing up, the omnibus analyses provide more conclusive support that the way in which response eccentricity modulates the orthogonal Simon effect is different from how it modulates the conceptual congruency effects between left-right space and both number and time.

7. General discussion

The present experiment series showed that the associations between space and numerical magnitude (SNARC) and associations between space and time are not significantly modulated by response eccentricity. We did observe a successful modulation of the orthogonal Simon effect (vertical-horizontal congruency) by our manipulation of response eccentricity in Experiment 1, which replicated in its general features the findings reported by Proctor and Cho (2003). Furthermore, we observed reliable space-number congruency effects in both parity and magnitude categorization tasks, and a space-time congruency effect in a time categorization task. When the three experiments including an abstract dimension (number or space) were analyzed together, response eccentricity still failed to modulate the congruency effects for number and time in spite of the increased statistical power. When the initial (orthogonal Simon) experiment was added to this omnibus analysis, a clear interaction between experiment, conceptual congruency and response eccentricity was revealed. All in all, present results show that response eccentricity does not affect conceptual congruency in a similar way to how it affects the orthogonal Simon effect. Given the expanded statistical power of the final analysis, we feel safe in concluding that, if there is any effect at all of response eccentricity on space-number and space-time congruency, it is likely to be of negligible size.

Proctor and colleagues (Cho and Proctor, 2003; Cho et al., 2008; Proctor and Cho, 2003; Weeks et al., 1995) accounted for eccentricity effects on the orthogonal Simon as a consequence of a change in polarity in the spatial left-right dimension: placing the response set on one side increases the saliency of that side, turning it effectively into the *+pole*. Then, this side now matches the *+pole* of the vertical dimension (up). If this interpretation is correct, and the SNARC effect is due to polarity correspondence between larger numbers and right responses, placing the response set on the left should reduce or even reverse the SNARC. A similar reasoning applies to the space-time congruency effect: if we assume that future related concepts are the *+pole* of the temporal dimension (at least when contrasted with past related concepts), placing the response set on the left should also reduce or even reverse the effect. However, we found no traces of any influence of response eccentricity on the space-number (SNARC) and space-time congruency effects. Present data are thus consistent with Shaki et al. (2012), who also failed to find any modulation of the SNARC effect in judgements of relative magnitude of digit pairs, in spite of strong changes on judgements of animals' relative size in an otherwise identical task.

What are the implications of the present findings? Not finding effects of polarity correspondence on space-number and space-time congruency effects is at odds with the polarity explanation provided for the SNARC effect by Proctor and Cho (2006); see also Santens and Gevers, 2008; Hutchinson and Louwerse, 2014; Nathan et al., 2009; Shaki et al., 2012; Ito and Hatta, 2004), and provides evidence against a polarity correspondence account of the space-number and space-time congruency effects. Is there a way the present data can be reconciled with a polarity correspondence account? One possibility is that the left-right axis is somehow impervious to polarity correspondence, in contrast to the congruency effects studied by Lakens (2012) and Lynott and Coventry (2014) which are related to the up-down axis. Some studies of the SNARC effect which have been interpreted as supporting polarity correspondence have indeed used spatial contrasts other than left-right (see Ito and Hatta, 2004, for up-down, or Santens and Gevers, 2008, for close-far). An explanation of the special status of the left-right dimension was proposed by Clark (1973), who argued that this dimension maybe intrinsically symmetrical and therefore lacks a polar structure. If there is no default polarity difference between left vs. right, this could explain the lack of a response eccentricity effect in Experiments 2–4. This account has two problems: first, it cannot account for studies such as Nathan et al. (2009) or Shaki et al. (2012), which tested the association of left-right space to smaller than – larger than judgments; and secondly and more importantly, it cannot explain why response eccentricity did affect the mapping between vertical and horizontal space in the orthogonal Simon task of Experiment 1.

A second possibility is that the response eccentricity manipulation was not strong enough to change the polarity structure of the conceptual dimensions. Lakens (2012) used a training task of 160 trials to influence polarity differences. Banks et al. (1975) changed the task instructions, and either referred to dots up and down on the screen as 'balloons' or as 'yoyo's', and successfully reversed the default polarity (up for balloons, down for yoyo's). It might be argued that such manipulations are stronger than the response eccentricity manipulation. Obviously, this second possibility also has the problem of accounting for the clear effects of response eccentricity in the orthogonal Simon task.

A third possibility, that should not be overlooked, is that the influence of response eccentricity on the orthogonal Simon effect is not due to polarity correspondence. In this case, present results would not be informative with regard to the polarity correspondence account. However, what such mechanism could be is unclear. Cho and Proctor (2003) discussed in detail why their account was to be preferred over several theoretical alternatives. Thus, although it remains as a logical possibility that response eccentricity does not change left-right polarities, we think it unlikely given the current state of knowledge.

A final possibility is that there are two types of mappings between concrete and abstract dimensions that differ in automaticity and flexibility. On one hand, mappings with left-right lateral space, which would be salient and relatively automatic, and therefore less flexible. On the other hand, mappings with up-down vertical space (and possibly other spatial contrasts), which could be very flexible (Lakens, 2012; Santiago et al., 2012). However, the causes of this difference in automaticity and flexibility between lateral and vertical mappings is currently unclear. It might be argued that numbers and space are truly analogue and continuous (numeric, temporal, or other) magnitudes, whereas valence and power are processed as dichotomous bi-polar opposites. However, this possibility contrasts with the finding of graded semantic distance effects on power (Chiao et al., 2004; Giessner and Schubert, 2007) and with categorical effects on number (Gevers et al., 2006). It might also be argued that the strength of lateral mappings is due to the existence of very consistent cultural conventions linked to reading and writing direction (e.g., number lines, charts, timelines, and so on). Yet, vertical mappings of power and valence are also supported by widespread, common, and possibly universal cultural conventions (Schubert, 2005). Finally, available evidence does not clearly support the hypothesized difference in automaticity-flexibility: some studies find quite automatic activation of space by numbers (Fischer et al., 2003 and time (Eikmeier et al., in press), whereas others find a flexible mapping for numbers (Bächtold et al., 1998; Fischer et al., 2010) and a non-automatic mapping for time (Ulrich and Maienborn, 2010; Ulrich et al., 2012).

Summing up, present results are difficult to reconcile with the polarity correspondence account of the space-number (SNARC) and space-time congruency effects. The possibilities that 1) the left-right spatial dimension is special and lacks a polar structure; and 2) the response eccentricity manipulation is not strong enough, both require additional assumptions to explain the effect of response eccentricity in the orthogonal Simon task, and it is currently unclear what those additional assumptions could be. The possibility that response eccentricity exerts its effect by means other than changing the polarities of the left-right axis is also rendered unconvincing by the lack of a better alternative mechanism. A final possibility is that there are intrinsic differences between, on one side, the mappings between lateral space and number or time, and on the other side, the mappings between vertical space and valence or morality, but what the nature of these differences is remains unclear. Future research will need to address whether it is necessary to distinguish two kinds of conceptual congruency effects (those that arise as a result of polarity correspondence, and those that do not), or whether it is better to dispose altogether of the polarity correspondence principle in the interpretation of conceptual congruency effects and look for a more general underlying mechanism of these effects.

8. Conclusions

All in all, present data let us conclude that the explicit prediction of the polarity correspondence view that the left-right space-number (SNARC) and space-time congruency effects should be modulated by response eccentricity in the same way as it modulates the orthogonal Simon effect does not hold. If there is any modulation at all of these effects due to response eccentricity, it is likely to be negligible. This suggests that the conceptual congruency effects between space and number or time do not arise as a result of polarity correspondence.

Acknowledgements

This research has been funded by grants P09-SEJ-4772 (Consejería de Innovación, Ciencia y Empresa, Andalusian Government) and PSI2012-32464 (Spanish Ministry of Economy and Competitivity). The authors want to thank Áurea Román Reche, Jose Isidro Martínez Cascales, and Juan Manuel de la Fuente, for their help in running the Spanish experiments.

Appendix A

Table 1
Cell means in the design of Experiment 1. Latencies are shown in milliseconds. Accuracy is shown within brackets.

		Keyboard location					
Vertical location	Response	Left		Centre		Right	
Up	Left	423	(0.99)	420	(0.99)	431	(0.99)
	Right	504	(0.97)	473	(0.97)	421	(0.99)
Down	Left	490	(0.93)	474	(0.95)	436	(0.98)
	Right	415	(1.00)	409	(0.99)	439	(0.98)

Table 2
Results of the ANOVA on the latency measure in Experiment 1. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	2.00	0.161	
Error	14			
Keyboard location	2	6.81	0.004	**
Keyboard location × Counterbalance	6	0.51	0.797	
Error	28			
Vertical location	1	0.04	0.844	
Vertical location × Counterbalance	3	0.66	0.592	
Error	14			
Response	1	0.40	0.538	
Response × Counterbalance	3	0.49	0.695	
Error	14			
Keyboard location × Vertical location	2	5.56	0.009	**
Keyboard location × Vertical location × Counterbalance	6	2.77	0.030	**
Error	28			
Keyboard location × Response	2	0.50	0.611	
Keyboard location × Response × Counterbalance	6	0.91	0.505	
Error	28			
Vertical location × Response	1	11.05	0.005	**
Vertical location × Response × Counterbalance	3	1.25	0.328	
Error	14			
Keyboard location × Vertical location × Response	2	25.73	0.000	**
Keyboard location × Vertical location × Response × Counterbalance	6	2.81	0.029	**
Error	28			

Table 3
Results of the ANOVA on the accuracy measure in Experiment 1. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	0.62	0.615	
Error	14			
Keyboard location	2	3.88	0.033	*
Keyboard location × Counterbalance	6	0.95	0.475	
Error	28			
Vertical location	1	14.38	0.002	**
Vertical location × Counterbalance	3	0.60	0.627	
Error	14			
Response	1	3.00	0.105	
Response × Counterbalance	3	0.19	0.901	
Error	14			
Keyboard location × Vertical location	2	0.94	0.404	
Keyboard location × Vertical location × Counterbalance	6	1.82	0.132	
Error	28			
Keyboard location × Response	2	2.80	0.078	
Keyboard location × Response × Counterbalance	6	0.63	0.702	
Error	28			
Vertical location × Response	1	7.85	0.014	*
Vertical location × Response × Counterbalance	3	0.04	0.990	
Error	14			
Keyboard location × Vertical location × Response	2	9.04	0.001	**
Keyboard location × Vertical location × Response × Counterbalance	6	0.54	0.777	
Error	28			

Table 4
Cell means in the design of Experiment 2. Latencies are shown in milliseconds. Accuracy is shown within brackets.

			Keyboard location					
Parity	Magnitude	Response	Left		Centre		Right	
Even	Smaller than 5	Left	554	(0.97)	556	(0.98)	545	(0.96)
		Right	551	(0.94)	544	(0.97)	556	(0.97)
	Larger than 5	Left	597	(0.95)	567	(0.96)	595	(0.95)
		Right	568	(0.96)	538	(0.97)	561	(0.96)
Odd	Smaller than 5	Left	574	(0.96)	574	(0.95)	593	(0.94)
		Right	574	(0.96)	580	(0.94)	579	(0.94)
	Larger than 5	Left	589	(0.94)	575	(0.96)	579	(0.95)
		Right	567	(0.96)	560	(0.95)	566	(0.96)

Table 5
Results of the ANOVA on the latency measure in Experiment 2. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p
Counterbalance	3	1.60	0.228
Error	16		
Keyboard location	2	1.77	0.187

Table 5 (*continued*)

Effect	deg	F	p	
Keyboard location × Counterbalance	6	3.96	0.004	**
Error	32			
Parity	1	13.52	0.002	**
Parity × Counterbalance	3	0.30	0.827	
Error	16			
Magnitude	1	2.87	0.110	
Magnitude × Counterbalance	3	0.23	0.873	
Error	16			
Response	1	9.30	0.008	**
Response × Counterbalance	3	2.17	0.131	
Error	16			
Keyboard location × Parity	2	1.41	0.259	
Keyboard location × Parity × Counterbalance	6	1.33	0.275	
Error	32			
Keyboard location × Magnitude	2	1.67	0.205	
Keyboard location × Magnitude × Counterbalance	6	1.17	0.345	
Error	32			
Parity × Magnitude	1	3.04	0.100	
Parity × Magnitude × Counterbalance	3	0.16	0.921	
Error	16			
Keyboard location × Response	2	0.18	0.837	
Keyboard location × Response × Counterbalance	6	1.04	0.418	
Error	32			
Parity × Response	1	0.10	0.753	
Parity × Response × Counterbalance	3	0.23	0.875	
Error	16			
Magnitude × Response	1	8.12	0.012	*
Magnitude × Response × Counterbalance	3	0.22	0.881	
Error	16			
Keyboard location × Parity × Magnitude	2	0.64	0.533	
Keyboard location × Parity × Magnitude × Counterbalance	6	0.79	0.582	
Error	32			
Keyboard location × Parity × Response	2	0.41	0.670	
Keyboard location × Parity × Response × Counterbalance	6	0.47	0.824	
Error	32			
Keyboard location × Magnitude × Response	2	0.01	0.986	
Keyboard location × Magnitude × Response × Counterbalance	6	0.97	0.459	
Error	32			
Parity × Magnitude × Response	1	0.31	0.583	
Parity × Magnitude × Response × Counterbalance	3	0.98	0.428	
Error	16			
Keyboard location × Parity × Magnitude × Response	2	0.75	0.479	
Keyboard location × Parity × Magnitude × Response × Counterbalance	6	2.66	0.033	*
Error	32			

Table 6

Results of the ANOVA on the accuracy measure in Experiment 2. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	0.52	0.672	
Error	16			
Keyboard location	2	0.64	0.536	
Keyboard location × Counterbalance	6	1.52	0.205	
Error	32			
Parity	1	9.50	0.007	**
Parity × Counterbalance	3	1.87	0.175	
Error	16			
Magnitude	1	0.06	0.804	
Magnitude × Counterbalance	3	0.56	0.648	
Error	16			
Response	1	0.23	0.638	
Response × Counterbalance	3	1.34	0.296	
Error	16			
Keyboard location × Parity	2	0.93	0.405	
Keyboard location × Parity × Counterbalance	6	1.55	0.193	
Error	32			
Keyboard location × Magnitude	2	0.37	0.692	
Keyboard location × Magnitude × Counterbalance	6	0.97	0.461	
Error	32			
Parity × Magnitude	1	0.21	0.651	
Parity × Magnitude × Counterbalance	3	0.72	0.552	
Error	16			
Keyboard location × Response	2	0.31	0.737	
Keyboard location × Response × Counterbalance	6	1.45	0.227	
Error	32			
Parity × Response	1	0.01	0.942	
Parity × Response × Counterbalance	3	0.71	0.559	
Error	16			
Magnitude × Response	1	0.86	0.369	
Magnitude × Response × Counterbalance	3	1.16	0.355	
Error	16			
Keyboard location × Parity × Magnitude	2	0.83	0.445	
Keyboard location × Parity × Magnitude × Counterbalance	6	1.03	0.422	
Error	32			
Keyboard location × Parity × Response	2	0.79	0.462	
Keyboard location × Parity × Response × Counterbalance	6	3.28	0.012	*
Error	32			
Keyboard location × Magnitude × Response	2	0.87	0.427	
Keyboard location × Magnitude × Response × Counterbalance	6	0.30	0.932	
Error	32			
Parity × Magnitude × Response	1	0.19	0.669	
Parity × Magnitude × Response × Counterbalance	3	0.90	0.463	
Error	16			
Keyboard location × Parity × Magnitude × Response	2	0.35	0.710	
Keyboard location × Parity × Magnitude × Response × Counterbalance	6	0.83	0.559	
Error	32			

Table 7

Cell means in the design of Experiment 3. Latencies are shown in milliseconds. Accuracy is shown within brackets.

			Keyboard location					
Parity	Magnitude	Response	Left		Centre		Right	
Even	Smaller than 5	Left	543	(0.95)	550	(0.95)	549	(0.96)
		Right	562	(0.93)	552	(0.97)	581	(0.97)
	Larger than 5	Left	560	(0.93)	565	(0.93)	567	(0.95)
		Right	549	(0.96)	522	(0.98)	539	(0.97)
Odd	Smaller than 5	Left	545	(1.00)	541	(1.00)	537	(1.00)
		Right	546	(0.97)	532	(0.95)	555	(0.99)
	Larger than 5	Left	558	(0.96)	545	(0.97)	545	(0.98)
		Right	516	(0.98)	515	(0.98)	519	(0.99)

Table 8

Results of the ANOVA on the latency measure in Experiment 3. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	1.63	0.222	
Error	16			
Keyboard location	2	0.72	0.494	
Keyboard location × Counterbalance	6	1.19	0.339	
Error	32			
Parity	1	20.34	0.000	**
Parity × Counterbalance	3	0.40	0.752	
Error	16			
Magnitude	1	3.24	0.091	
Magnitude × Counterbalance	3	2.47	0.100	
Error	16			
Response	1	2.38	0.142	
Response × Counterbalance	3	1.08	0.384	
Error	16			
Keyboard location × Parity	2	0.68	0.515	
Keyboard location × Parity × Counterbalance	6	1.46	0.2231	

Table 8 (*continued*)

Effect	deg	F	p	
Error	32			
Keyboard location × Magnitude	2	0.95	0.397	
Keyboard location × Magnitude × Counterbalance	6	0.79	0.588	
Error	32			
Parity × Magnitude	1	0.22	0.649	
Parity × Magnitude × Counterbalance	3	0.72	0.554	
Error	16			
Keyboard location × Response	2	2.56	0.093	
Keyboard location × Response × Counterbalance	6	0.87	0.526	
Error	32			
Parity × Response	1	1.72	0.208	
Parity × Response × Counterbalance	3	1.00	0.420	
Error	16			
Magnitude × Response	1	6.55	0.021	*
Magnitude × Response × Counterbalance	3	1.79	0.190	
Error	16			
Keyboard location × Parity × Magnitude	2	0.20	0.817	
Keyboard location × Parity × Magnitude × Counterbalance	6	0.72	0.637	
Error	32			
Keyboard location × Parity × Response	2	1.06	0.357	
Keyboard location × Parity × Response × Counterbalance	6	0.73	0.631	
Error	32			
Keyboard location × Magnitude × Response	2	0.21	0.815	
Keyboard location × Magnitude × Response × Counterbalance	6	1.33	0.271	
Error	32			
Parity × Magnitude × Response	1	0.93	0.350	
Parity × Magnitude × Response × Counterbalance	3	1.74	0.200	
Error	16			
Keyboard location × Parity × Magnitude × Response	2	0.71	0.501	
Keyboard location × Parity × Magnitude × Response × Counterbalance	6	1.97	0.100	
Error	32			

Table 9
Results of the ANOVA on the accuracy measure in Experiment 3. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	0.71	0.558	
Error	16			
Keyboard location	2	3.12	0.058	
Keyboard location × Counterbalance	6	0.57	0.754	
Error	32			
Parity	1	10.15	0.006	**
Parity × Counterbalance	3	0.05	0.985	
Error	16			
Magnitude	1	0.23	0.640	
Magnitude × Counterbalance	3	0.09	0.962	
Error	16			
Response	1	1.69	0.212	
Response × Counterbalance	3	1.12	0.371	
Error	16			
Keyboard location × Parity	2	2.62	0.088	
Keyboard location × Parity × Counterbalance	6	1.54	0.196	
Error	32			
Keyboard location × Magnitude	2	0.71	0.499	
Keyboard location × Magnitude × Counterbalance	6	1.12	0.375	
Error	32			
Parity × Magnitude	1	0.30	0.590	
Parity × Magnitude × Counterbalance	3	1.96	0.161	
Error	16			
Keyboard location × Response	2	0.36	0.701	
Keyboard location × Response × Counterbalance	6	1.19	0.334	
Error	32			
Parity × Response	1	7.32	0.016	*
Parity × Response × Counterbalance	3	0.58	0.636	
Error	16			
Magnitude × Response	1	4.04	0.062	
Magnitude × Response × Counterbalance	3	1.27	0.319	
Error	16			
Keyboard location × Parity × Magnitude	2	0.88	0.423	

Table 9 (*continued*)

Effect	deg	F	p
Keyboard location × Parity × Magnitude × Counterbalance	6	1.74	0.144
Error	32		
Keyboard location × Parity × Response	2	2.10	0.139
Keyboard location × Parity × Response × Counterbalance	6	0.33	0.915
Error	32		
Keyboard location × Magnitude × Response	2	1.91	0.164
Keyboard location × Magnitude × Response × Counterbalance	6	0.70	0.655
Error	32		
Parity × Magnitude × Response	1	0.00	1.000
Parity × Magnitude × Response × Counterbalance	3	0.26	0.850
Error	16		
Keyboard location × Parity × Magnitude × Response	2	0.37	0.693
Keyboard location × Parity × Magnitude × Response × Counterbalance	6	1.01	0.434
Error	32		

Table 10
Cell means in the design of Experiment 4. Latencies are shown in milliseconds. Accuracy is shown within brackets.

		Keyboard location					
Time	Response	Left		Centre		Right	
Past	Left	660	(0.97)	649	(0.97)	670	(0.96)
	Right	697	(0.96)	694	(0.95)	736	(0.95)
Future	Left	685	(0.95)	672	(0.94)	699	(0.95)
	Right	648	(0.96)	644	(0.96)	651	(0.96)

Table 11
Results of the ANOVA on the latency measure in Experiment 4. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p	
Counterbalance	3	3.07	0.058	
Error	16			
Keyboard location	2	4.26	0.023	*
Keyboard location × Counterbalance	6	4.15	0.003	**
Error	32			
Time	1	5.58	0.031	*
Time × Counterbalance	3	0.48	0.704	
Error	16			
Response	1	0.45	0.510	
Response × Counterbalance	3	0.37	0.778	
Error	16			
Keyboard location × Time	2	0.66	0.525	
Keyboard location × Time × Counterbalance	6	1.24	0.312	
Error	32			
Keyboard location × Response	2	0.35	0.704	
Keyboard location × Response × Counterbalance	6	0.45	0.840	
Error	32			
Time × Response	1	7.37	0.015	*
Time × Response × Counterbalance	3	1.39	0.283	
Error	16			
Keyboard location × Time × Response	2	1.17	0.323	
Keyboard location × Time × Response × Counterbalance	6	1.45	0.226	
Error	32			

Table 12
Results of the ANOVA on the accuracy measure in Experiment 4. * means $p < .05$; ** means $p < .01$.

Effect	deg	F	p
Counterbalance	3	1.00	0.417
Error	16		
Keyboard location	2	0.99	0.382
Keyboard location × Counterbalance	6	2.22	0.067
Error	32		

(continued on next page)

Table 12 (*continued*)

Effect	deg	F	p
Time	1	1.09	0.311
Time × Counterbalance	3	2.55	0.092
Error	16		
Response	1	0.02	0.894
Response × Counterbalance	3	2.10	0.141
Error	16		
Keyboard location × Time	2	0.31	0.733
Keyboard location × Time × Counterbalance	6	0.86	0.537
Error	32		
Keyboard location × Response	2	0.35	0.711
Keyboard location × Response × Counterbalance	6	1.41	0.243
Error	32		
Time × Response	1	2.48	0.135
Time × Response × Counterbalance	3	0.85	0.487
Error	16		
Keyboard location × Time × Response	2	0.33	0.722
Keyboard location × Time × Response × Counterbalance	6	1.18	0.342
Error	32		

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