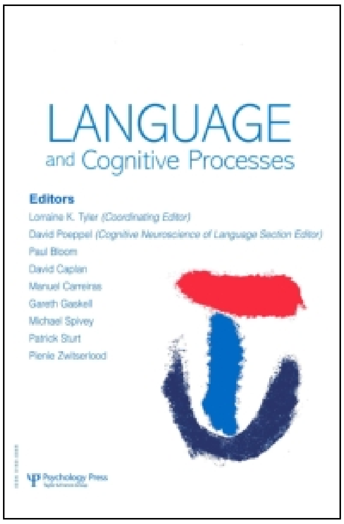

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Dimensions and their poles: A metric and topological approach to opposites

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Dimensions and their poles: A metric and topological approach to opposites

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We explored the nature of 37 spatial dimensions in Italian, such as LUNGO–CORTO (LONG–SHORT), INIZIO–FINE (BEGINNING–END), and CONVERGENTE–DIVERGENTE (CONVERGENT–DIVERGENT). In Study 1 we investigated their metric structure. We asked: (1) Are the extensions of the two poles (P_1 and P_2) the same? (2) What proportion of each dimension can be said to be *neither* P_1 *nor* P_2? and (3) Is the extension of P_1 that can be called *neither* P_1 *nor* P_2, the same as the extension of P_2 that can be called *neither* P_1 *nor* P_2? In Study 2 we investigated the topological structure of the dimensions. We asked: (1) Are the poles, points or ranges? (2) Do intermediates (*neither* P_1 *nor* P_2) exist? and (3) If they do, are they points or ranges?

Two metric properties explained a considerable proportion of the variation in the responses in the first task: (1) the asymmetry of the extension of the two poles and (2) the extension of the "neither–nor" region between them. The results of the topological task further refined the two-dimensional structure obtained in Study 1 to produce a *map of spatial opposites.*

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Michael Kubovy joined as third author after the experiments had been conceived, the data had been collected and analyses of these data had been published in Italian (some peer-reviewed journals). Together we reconceptualized the problem, and conducted new analyses of the data. Michael Kubovy's work is supported by NEI and NIDCD. Unless otherwise mentioned, we did all the analyses reported here using the base packages of *R* (Ihaka & Gentleman, 1996; R Development Core Team, 2010). We are grateful for the comments of J. T. Cargile, W. Epstein, S. Gepshtein, S. Glucksberg, M. S. Green, J. Shatin, W. T. Wojtach, and the assistance of S. Dray.

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Our methods and the resulting maps provide a point of departure from which two questions can be investigated: (1) If these methods were used in other languages to study spatial opposites, to what extent would they produce similar maps of opposites? and (2) If these methods were applied to nonspatial opposites and maps analogous to our spatial maps were generated, would any dense regions in the nonspatial maps coincide with sparse regions in the spatial maps? We discuss the potential importance of these questions.

Keywords: Opposites; Dimensions; Spatial; Metric and topological.

Opposites and bipolar dimensions have been pervasive in human thought. They were, for example, of fundamental importance both to Greek (Lloyd, 1966/1992) and Chinese philosophy (Fung, 1948/1976).

In psychology, the relation between dimensions and opposites has generally been thought to be simple: the endpoints or *poles* of a dimension are opposites. Between these poles, the quantities that characterise these dimensions have been considered to form at least ordinal scales (Clark, 1993). Data obtained using rating scales are analysed as if they directly represented a psychological interval scale (Breivik, Bjornsson, & Skovlund, 2000; Rosnow, 2000) or manifestations of psychological latent scales (Givon & Shapira, 1984; Mair & Hatzinger, 2007).

THE NATURE OF INTERMEDIATES

Ogden (1932/1967) was perhaps the first to observe that such a conception of the relations between dimensions and opposites may be insufficient. He distinguished between two types of opposites: (1) *series opposites*, the poles on either end of a dimension and (2) *cut opposites*, which he illustrated as follows:

> If we decide that inside and outside are opposites generated by a cut, there is no question of a series, and the one side is finite and the other side is infinite; for although we can speak of "further inside" or distinguish degrees of exteriority, thus making quantitative gradations on either side of the dividing line, this is a secondary consideration, and it is significant that the opposition begins, as it were, *immediately* the line is crossed. (Ogden, 1932/1967, p. 58)

This distinction is parallel to the linguistic distinction between opposites involving a pair of gradable adjectives, such as DIRTY–CLEAN, and complementary opposites, such as DEAD–ALIVE. DIRTY and CLEAN are called gradable adjectives because they: (1) admit *degree modifiers* (such as *fairly*, *very*, and *extremely*) and (2) can be *used comparatively* (*cats are* CLEAN*er than dogs*). In contrast, DEAD and ALIVE are called complementary opposites, because they do not admit degree modifiers, and cannot be used comparatively (Kennedy & McNally, 2005; Willners & Paradis, 2006). For example, it would be unusual to say *Mayan is a very* DEAD *language* (although it could be taken as irony), or *Latin is not as* DEAD *as Mayan* (although it could be understood metaphorically).

As it turns out, further distinctions among gradable opposites are needed (Cruse & Togia, 1995). We expect gradable adjectives to have a middle term. For example, if something is not HOT, it could be any temperature from WARM to COLD. However, the DIRTY–CLEAN dimension, which (as we saw earlier) is gradable, does not have a middle term. Whenever we say that something is not CLEAN, we might as well say that it is DIRTY.

Likewise complementaries, which are not supposed to have a middle term, may be used as if they were gradable: we might say that someone is *barely* ALIVE.

Thus a theory of opposites must have the means to capture a variety of intermediates. It must be able to describe dimensions that behave like a continuum, such as HOT–COLD, those that do not have a middle term, such as DIRTY–CLEAN, and those that straddle a cut, such as INSIDE–OUTSIDE.

THE NATURE OF POLES AND CUTS

To capture the nature of opposites we must also characterise the poles themselves (Kennedy, 2007; Kennedy & McNally, 2005). Modifying the Kennedy (2007) terminology slightly, we can distinguish between: (1) *closed poles*, which are the minimum or the maximum of a scale, such as closed in OPEN–CLOSED or both EMPTY and FULL in EMPTY–FULL and (2) *open poles*, which are unbounded, such as tall in SHORT–TALL (for related ideas, see Gardenfors, 2000, 2007).

Kennedy's idea invokes basic topology (Weisstein, 2008), which can be applied to understanding opposites. Beginning with a continuous line, we delimit a portion of it by two *endpoints*, *a* and *b*, to create an *interval*. Each endpoint can be a pole or a cut.

Figure 1 shows six kinds of intervals. If *a* and *b* are included in the interval (so that it consists of the points $a \leq x \leq b$), the interval is called *closed*, and is denoted $[a, b]$ (Figure 1a). If neither *a* nor *b* is included (it consists of the points $a < x < b$), the interval is called *open*, and is denoted (a, b) (Figure 1b).

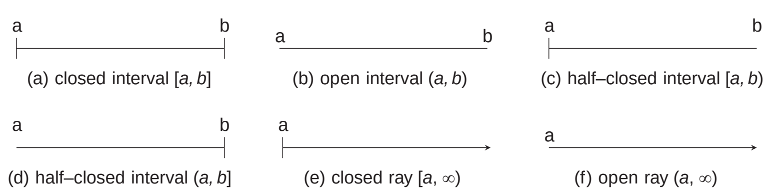


Figure 1. Six types of intervals.

If a is included and b is not ($a \leq x < b$) or vice-versa ($a < x \leq b$), the interval is called *half-closed*, and is denoted $[a, b)$ or $(a, b]$ (Figure 1c and d). If one of the endpoints is $\pm\infty$, then the interval is called a *ray.* If a ray includes the finite endpoint, it is a *closed ray* and is denoted $[a, \infty)$ (Figure 1e); if it doesn't, it is an *open ray* denoted (a, ∞) (Figure 1f). (A single point is treated as a *degenerate interval*, denoted $[a, a]$.)

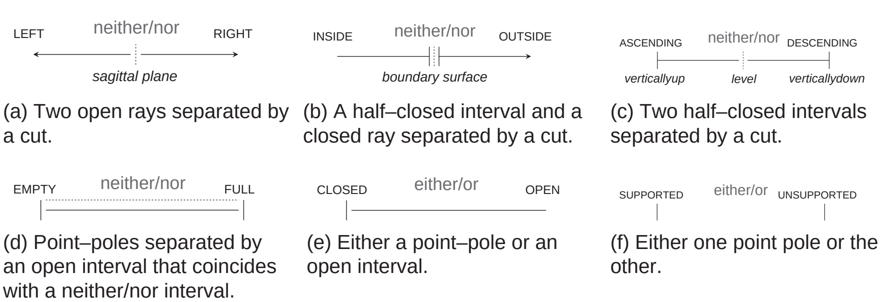
THEORY

We propose to discover the psychological structure of dimensions by considering two types of properties: (1) topological and (2) metric.

Topological considerations

Using the topological tools just described, we can identify six types of spatial dimensions, shown in Figure 2. Each pole can be:

- *an open ray*, such as in LEFT, RIGHT (Figure 2a). In this example, one pole approaches the other at a point of reference, which *is not an element of either pole*. In the case of LEFT–RIGHT, this point represents a surface, which is the *sagittal plane*, the plane of symmetry of a mirror-symmetric body that has a front and a back.
- *a half-closed interval*, such as ASCENDING or DESCENDING (Figure 2c). Each of these poles includes its maximum: neither one can ascend more steeply than vertically, nor can one descend more steeply than vertically. As in the previous cases there is a point of reference, which is neither ASCENDING nor DESCENDING.
- *a closed ray*, such as the OUTSIDE pole of the INSIDE–OUTSIDE pair (Figure 2b). Here the boundary (such as a wall) is often thought to belong to this pole. For example, a vine climbing on a wall of a house is on the wall and yet outside the house.



(a) Two open rays separated by a cut.

(b) A half–closed interval and a closed ray separated by a cut.

(c) Two half–closed intervals separated by a cut.

(d) Point–poles separated by an open interval that coincides with a neither/nor interval.

(e) Either a point–pole or an open interval.

(f) Either one point pole or the other.

Figure 2. Six examples of dimensions.

- *a point*, such as EMPTY, FULL, CLOSED, SUPPORTED, and UNSUPPORTED. Consider the EMPTY–FULL pair (Figure 2d): when even *an infinitesimal quantity* is introduced into the container it is neither EMPTY nor FULL. Furthermore, until it is FULL to the brim it remains neither EMPTY nor FULL. Thus here the neither/nor interval is identical with the interval between the two poles. Similarly, CLOSED is a point, since when a container or a barrier is even infinitesimally opened, it is OPEN (Figure 2e). An analogous argument holds for SUPPORTED and UNSUPPORTED (Figure 2f).

Between the poles there can be the following relations (Figure 3):

- they allow for intermediate states (Figure 2a–d). Among these *neither/nor* sets we can distinguish two classes: neither/nor is an
  - isolated state (Figure 2a–c) and
  - open interval (Figure 2d).
- they do not allow for intermediate states, i.e., either one pole or the other is the case (Figure 2e and f).

Metric considerations

Compare the dimensions LEFT–RIGHT and SMALL–LARGE. As Figure 2 shows, the former is symmetric. We tend to think that the range of things on our right and the range of things on our left are equal. However, it is likely that we think that the scope of large things is greater than the scope of small things. If, for example, we asked ourselves how to partition a line to represent this imbalance, we might expect to see something like Figure 4. In this Figure, the interval between SMALL and LARGE, denoted Γ, has been partitioned into two unequal intervals, γ and $\overline{\gamma}$. (There also might be an asymmetry between the scope of things that are neither SMALL nor LARGE. We will show how to address this question and the question of measuring asymmetries empirically later, when we describe the experiments.)

To make the idea of asymmetry more precise, we need to consider in what sense there may be fewer things that are SMALL than things that are LARGE.

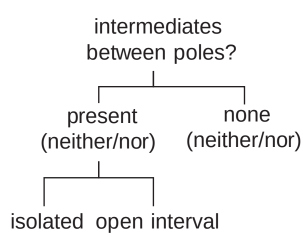


Figure 3. The three types of intermediates between poles.

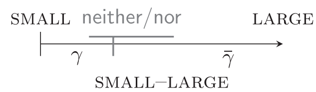


Figure 4. Asymmetry: γ is the interval in which we would rather call something SMALL than LARGE; $\overline{\gamma}$ is the interval in which we would rather call something LARGE than SMALL; and Γ is the range of sizes of things to which we might apply the adjectives SMALL or LARGE.

We do not mean the number of objects we encounter that are small or large; it is likely that we interact more frequently with small things than with large ones. Nor do we mean the number of *types* of objects we encounter that are small or large; it is also likely that we interact more frequently with small types of things than with large ones.

Rather the question is, How to put these objects or types of objects into a finite number of bins? The problem is closely related to the statistical problem of determining how to assign continuous data to bins in a histogram. In Figure 5 we compare two histograms (based on an example of Fox, 2002, §3.1.1) in which the boundaries between bins in the histogram on the left were chosen to be "pretty" numbers, and the boundaries between bins in the histogram on the right were chosen to maximise informativeness. As a consequence, potentially important details obscured in the left-hand histogram, become visible in the right-hand histogram.

We are proposing that the intuition that $\overline{\gamma}$ is wider than γ is based on the number of bins we tend assign to γ (N_γ) and to $\overline{\gamma}$ ($N\overline{\gamma}$), leading us to partition

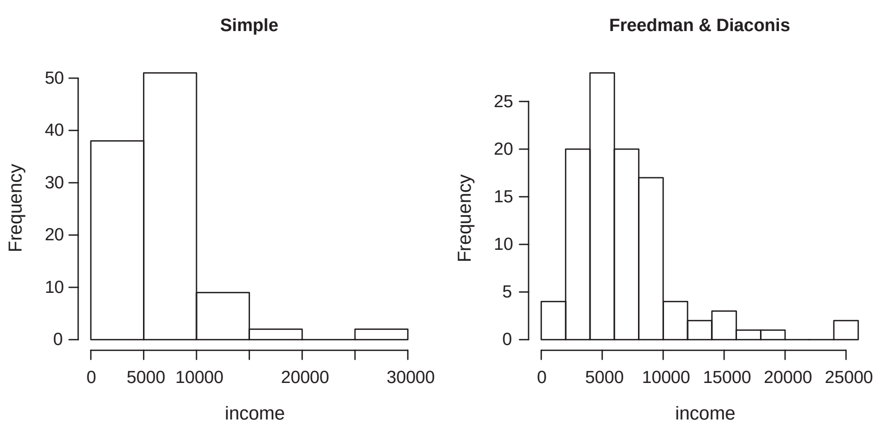


Figure 5. Two histograms of the average income of job holders, in Canadian dollars, in 1971 (Fox, 2002, §3.1.1). In the case labelled "Simple", the number of bins is $N = \lfloor 10 \log(10n) \rfloor$; in the case labelled "Freedman and Diaconis (1981)", $N = \dfrac{n^{1/3}R}{2\ \mathrm{IQR}}$, where $\lfloor\ \rfloor$ is the symbol for the *floor* operation, n is the number of observations, R is the range of X, and IQR is the inter-quartile range of X.

the dimension in the proportion $\gamma/\overline{\gamma} = N_\gamma/N\overline{\gamma}$. But how to interpret these bins? We think of them as Γ-*experience bins*.

Suppose γ is SMALL, $\overline{\gamma}$ is LARGE, and the dimension is size, which is continuous. Consider two ants: one large and the other small. Since you can readily tell that one is bigger than the other you would say that they differ in size. If, however, you were asked whether there was a qualitative size difference between them, taking into account the range of all object sizes, from the smallest thing you can see (say, a grain of sand) to the biggest thing you can see (perhaps a tall and wide rock wall that exceeds your visual field), you might choose to place them in the same size-experience bin. On the other hand, you might decide that because there is a qualitative size difference between the size of ants and the size of butterflies or nuts, they belong in different size-experience bins, whereas you might assign butterflies and nuts to the same size-experience bin.

Once the concept of Γ-experience bins is clear, it is not difficult to take the next step: estimate the number of Γ-experience bins to which the adjective γ applies better, N_γ, and the number of Γ-experience bins to which the adjective $\overline{\gamma}$ applies better, $N\overline{\gamma}$. The value of $N_\gamma/N\overline{\gamma}$ allows us to partition Γ.

Preview and rationale of methods

In this article, we report on three studies to investigate opposition. Several assumptions underlie the design of these studies. We first describe each noteworthy feature of these studies, and then explain why it was chosen rather than a more conventional design.

Participants and setting

The participants were undergraduate students at the Milan Institute of Technology. This was a class project that took place at the very beginning of a course on *The psychology of space perception and representation*, before opposites were discussed in class.

Since the authors entertained no hypotheses regarding the structures that would emerge, the participants were naive. The participants were not randomly sampled from the population, which is true of most—if not all—psychological experiments. However, the choice of this group maximised the likelihood that the participants were interested in the topic at hand. Furthermore, because they would eventually be involved in discussions of the results, there was reason to believe that they were willing to invest considerable effort in the tasks. Indeed the three studies collectively took 13.5 hours. Using motivated participants, such as the authors themselves, is common in psychophysics (e.g., Cass, Stuit, Bex, & Alais, 2009; Hecht, Shlaer, & Pirenne, 1941).

Performance in groups

The studies were conducted in a large classroom, equipped with long tables (about 1 × 5 m) on which had been placed large blank sheets (A3) of writing paper. They divided themselves into groups of three or four and sat far enough so as not to influence each other. We considered these 19 groups as the units of our study.

There is evidence that group performance is superior to individual performance (Kocher & Sutter, 2005; Liang, Moreland, & Argote, 1995), that they more readily overcome fixation in problem-solving (Smith, Bushouse, & Lord, 2010, also known as functional fixedness, Duncker, 1945), they are more creative (De Dreu, Nijstad, & van Knippenberg, 2008), and that a group size of three to four is optimal (Wheelan, 2009). Most important, "groups generally decrease variability in the way information is processed, compared with individuals" (Hinsz, Tindale, & Vollrath, 1997).

Instructions

At the beginning of the first session, the experimenters explained that they wanted the participants to help them discover the basic properties of space. In order to draw upon a broad spectrum of spatial experiences, they asked participants to base their list of spatial properties on: (1) What they could see around them: "Look at things in this room and notice their spatial properties as well as the spatial relations between them. You should also consider what you can see through the windows" and (2) What they could not see at the moment: "Consider also environments that you cannot see right now. For instance, you might consider the spatial properties and relations you see when you look out of the windows of the upper floor of this building or when you're in the subway, or when you're on the beach, looking at the horizon. Since the final list must be consensual, and should only include properties on which all of you agree, be sure not to add an item to the list unless everyone grasps exactly what it means". The experimenters made it clear that they were neither asking them about the semantics of Italian nor about the metaphorical use of spatial terms (e.g., "I feel *marginalised"* and "I feel *close* to my best friend").

Focus on spatial dimensions

The three studies focus on spatial dimensions for two reasons: (1) it was pragmatically convenient to restrict the study to a familiar and well-defined set of dimensions and (2) the perception and description of space are of interest in their own right (Coventry & Garrod, 2004; Landau & Jackendoff, 1993; Talmy, 1983).

Phenomenology

In these studies we used incorrigible phenomenological reports. This is not uncommon in psychology: any time we use a Likert scale we accept the participants' marks on the scale at face value. Indeed, this work is an instance of "phenomenological psychophysics" (Kubovy, 2003), which is related to the experimental phenomenology of Bozzi (1989, Chapter 7, summarised by Kubovy, 1999, and discussed in relation to the present task by Savardi & Bianchi, 2000). Our methods are (to paraphrase Kubovy & Gepshtein, 2003, p. 45) "phenomenological: they rely on the reports of observers about their phenomenal experiences. They also are psychophysical: they involve systematic exploration of stimulus spaces and quantitative representation of perceptual responses to variations in stimulus parameters".

Are we asking for linguistic intuitions?

In the preliminary study—where we ask the participants to give us pairs of opposites—we are. However, as will become clear later, in the subsequent studies the instructions emphasised that the tasks were to be done in relation to *spatial experiences*; Italian semantics were not mentioned, nor did any of the participants raise the question. Nevertheless, in the absence of a manipulation check, this question must remain unanswered. We return to this issue in Section "General Discussion".

PRELIMINARY STUDY: SPATIAL PROPERTIES AND RELATIONS

In our preliminary study, we obtained our list of spatial dimensions and opposites. The 57 participants divided themselves into 19 groups. The experimenters asked each group to produce a consensual list of as many spatial properties as possible without being redundant. They pointed out that this was not something the participants could know from the outset, and that the answers would emerge from their collective effort. They did their best to create a collaborative and informal atmosphere and gave the groups as much time as they needed (about 90 min).

They asked the groups to produce lists that were exhaustive, so that they contained all the terms needed to describe any spatial environment. Most of the interactions among the members of the groups were devoted to describing different spatial environments and objects and finding the best term to refer to a property and eliminating synonyms (e.g., "long" vs. "elongated", "big" vs. "enormous", and "angular" vs. "peaked" vs. "sharp").

The groups collectively produced lists of 60 and 80 terms. After synonyms were removed, a list of 74 terms was compiled from words mentioned by at least 80% of the groups. For the most part, these were adjectives or adverbs. They fell into four groups: (1) shape of space; (2) orientation; (3) extension/ quantity; and (4) localisation. Each of the properties mentioned had its opposite within this list. The 74 terms were arranged in 37 pairs (Table 1).

STUDY 1: THE METRIC STRUCTURE OF DIMENSIONS

Method

About 41 of the undergraduates from the preliminary study participated in two three-hour sessions, in successive weeks. They were randomly assigned to 10 groups of four and one group of five, and were tested concurrently in the same room.

Each group was given a sheet of 37 labelled scales (Figure 6). At the ends of each scale were labels representing spatial opposites. The distance between the endpoints (10 cm), represented the range of spatial experiences between these opposites (or in other words the dimension). Each scale consisted of two stacked rectangles. The order of the dimensions within each list and of the poles within each dimension was randomised between groups.

The participants were given two tasks, each of which focused on a different aspect of the dimension's structure.

Task 1

In the first task, they were asked to draw a vertical boundary between opposites in the upper rectangle (Figure 7). Take, for example, the near–far dimension. It was made clear that they had to mark this line taking into account that the total length of the scale represented the whole range of variations of distances of things between the nearest and the farthest.

To carry out the task, the participants were asked to first consider objects in the classroom. They were invited to interact with these objects. For example, they could vary the openness of a door while discussing OPEN–CLOSED, or to place objects of different sizes on the table while considering SMALL–LARGE. They were not, however, restricted to discussing objects that were present.

The instructions stressed that we did not want them to rely on their knowledge of the true physical measures of objects, but rather on how these objects normally appeared. For instance, although *we know* that stars are huge, they *look* small. They might therefore fall into the same size-experience bin as a fly.

As we mentioned earlier this task is an instance of phenomenological psychophysics. It differs from psychophysics because it offers no correct or incorrect responses. Nevertheless, this work is not unlike scaling in the tradition of Fechner: to develop a scale of size, one might measure a succession of jnds between objects of similar sizes. In contrast, our Γ scale

TABLE 1
Characteristics of opposition pairs

	$\gamma - \overline{\gamma}$		Abbreviation	l	r	ll	rr	m	lln	rrn	asym2	asym3
1	dentro–fuori	inside–outside	INSD–OTSD	0.50	0.50	0.47	0.44	0.099	0.93	0.88	0.079	0.077
2	appoggiato–sospeso	supported–unsupported	SPPR–UNSP	0.51	0.49	0.48	0.47	0.045	0.95	0.96	0.057	0.026
3	sdraiato–in piedi	lying down–standing	LYND–STND	0.52	0.48	0.15	0.31	0.540	0.29	0.65	0.129	0.359
4	illimitato–limitato	unbounded–bounded	UNBN–BNDD	0.52	0.48	0.50	0.45	0.050	0.95	0.94	0.113	0.043
5	destra–sinistra	right–left	RGHT–LEFT	0.52	0.48	0.47	0.43	0.100	0.90	0.90	0.040	0.012
6	spigoloso–arrotondato	angular–rounded	ANGL–RNDD	0.55	0.45	0.47	0.40	0.122	0.86	0.89	0.108	0.082
7	a fondo–a galla	sunken–floating	SNKN–FLTN	0.55	0.45	0.20	0.21	0.590	0.37	0.46	0.104	0.139
8	verticale–orizzontale	vertical–horizontal	VRTC–HRZN	0.57	0.43	0.30	0.34	0.362	0.51	0.76	0.194	0.298
9	convesso–concavo	convex–concave	CNVX–CNCV	0.57	0.43	0.55	0.41	0.037	0.96	0.96	0.145	0.033
10	fine–inizio	end–beginning	END–BGNN	0.57	0.43	0.13	0.25	0.623	0.23	0.58	0.173	0.344
11	dritto–rovescio	upright–upside down	UPRG–UPSD	0.58	0.42	0.51	0.34	0.143	0.89	0.81	0.180	0.102
12	divergente–convergente	divergent–convergent	DVRG–CNVR	0.58	0.42	0.55	0.39	0.055	0.96	0.93	0.173	0.030
13	sopra–sotto	above–below	ABOV–BELW	0.59	0.41	0.47	0.33	0.202	0.80	0.79	0.177	0.076
14	in salita–in discesa	ascending–descending	ASCN–DSCN	0.59	0.41	0.50	0.36	0.139	0.84	0.89	0.187	0.065
15	complesso–semplice	complex–simple	CMPL–SMPL	0.59	0.41	0.36	0.25	0.388	0.60	0.62	0.189	0.135
16	davanti–dietro	in front of–behind	INFO–BHND	0.60	0.40	0.56	0.37	0.068	0.94	0.92	0.196	0.030
17	lontano–vicino	far–near	FAR–NEAR	0.61	0.39	0.33	0.35	0.317	0.55	0.89	0.222	0.351
18	ottuso–acuto	obtuse–acute	OBTS–ACUT	0.61	0.39	0.54	0.31	0.152	0.88	0.80	0.225	0.134
19	in cima–in fondo	top–bottom	TOP–BTTM	0.62	0.38	0.31	0.10	0.593	0.49	0.26	0.239	0.239
20	grasso–magro	fat–slender	FAT–SLND	0.63	0.37	0.46	0.22	0.319	0.74	0.58	0.259	0.172
21	asimmetrico–simmetrico	asymmetric–symmetric	ASYM–SYMM	0.64	0.36	0.52	0.34	0.140	0.82	0.92	0.274	0.130
22	ampio–ristretto	ample–restricted	AMPL–RSTR	0.65	0.35	0.42	0.24	0.336	0.64	0.70	0.304	0.098
23	lungo–corto	long–short	LONG–SHRT	0.66	0.34	0.44	0.22	0.337	0.67	0.64	0.323	0.095
24	grande–piccolo	large–small	LARG–SMLL	0.66	0.34	0.44	0.21	0.344	0.67	0.64	0.328	0.136
25	disordinato–ordinato	disordered–ordered	DSRD–ORDR	0.67	0.33	0.52	0.28	0.195	0.79	0.84	0.334	0.119
26	tanto–poco	many–few	MANY–FEW	0.67	0.33	0.43	0.30	0.267	0.65	0.92	0.341	0.278
27	spesso–sottile	thick–thin	THCK–THIN	0.70	0.30	0.52	0.18	0.299	0.75	0.60	0.397	0.153

TABLE 1 (*Continued*)

	$\gamma - \overline{\gamma}$		Abbreviation	l	r	ll	rr	m	lln	rrn	asym2	asym3
28	pieno–vuoto	full–empty	FULL–EMPT	0.70	0.30	0.29	0.12	0.587	0.42	0.40	0.399	0.144
29	alto–basso	high–low	HIGH–LOW	0.71	0.29	0.47	0.20	0.328	0.66	0.70	0.417	0.165
30	irregolare–regolare	irregular–regular	IRRG–RGLR	0.74	0.26	0.58	0.20	0.222	0.78	0.70	0.470	0.246
31	profondo–superficiale	deep–shallow	DEEP–SHLL	0.74	0.26	0.39	0.18	0.426	0.53	0.69	0.474	0.248
32	fitto–rado	dense–sparse	DENS–SPRS	0.75	0.25	0.38	0.22	0.400	0.50	0.88	0.502	0.395
33	storto–diritto	curved–straight	CRVD–STRG	0.75	0.25	0.64	0.22	0.137	0.86	0.88	0.504	0.131
34	largo–stretto	wide–narrow	WIDE–NRRW	0.76	0.24	0.55	0.13	0.319	0.72	0.55	0.524	0.204
35	incompleto–completo	incomplete–complete	INCM–CMPL	0.80	0.20	0.67	0.16	0.167	0.84	0.82	0.608	0.169
36	mosso–immobile	moving–still	MVNG–STLL	0.84	0.16	0.82	0.15	0.029	0.97	0.97	0.685	0.045
37	aperto–chiuso	open–closed	OPEN–CLSD	0.87	0.13	0.76	0.10	0.135	0.87	0.83	0.739	0.157

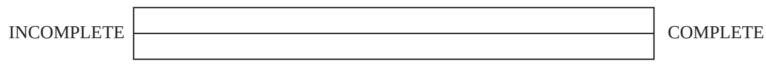


Figure 6. Example of a blank scale used for both tasks in Study 1.

is an ordinal scale that consists of a succession of equivalence sets, that we call size bins, and are quantitatively ordered. Each size bin is supposed to contain categories of object-size-experiences that are deemed by judges to be homogeneous, even though their sizes may be noticeably different.

Task 2

As we mentioned earlier, *not* HOT is not the same as it's opposite, COLD (Paradis & Willners, 2006). Likewise, *not* WIDE (Table 1, Line 34) is not the same as NARROW. This suggests that some dimensions can be subdivided further.

In the second task, we assessed the proportion of the dimension that is neither γ (e.g., *not* WIDE, denoted $\neg\gamma$) nor $\bar{\gamma}$ (e.g., *not* NARROW, denoted $\neg\bar{\gamma}$): $\overline{\gamma\bar{\gamma}}$ (e.g., *neither* WIDE–*nor* NARROW). To respond, the participants drew two lines in the bottom rectangle, on either side of the line drawn in the upper rectangle, to indicate this proportion. These lines were not required to be equidistant from the first (see Figures 7 and 8).

Results and discussion

From the data obtained in the two tasks (e.g., Figure 8) we calculated the nine quantities in Table 2 (their means are given in Table 1). For further analysis we chose five nonredundant measures (i.e., they are sufficient to calculate the other four measures, and cannot be derived from each other): m, asym2, lln, rrn, and asym3.

Although the five measures used in our analyses could have been independent, a correlation matrix shows that they are not. Although asym2 is by and large independent of the others, with median $(|r|) = 0.08$, the correlations among the remaining four are high: median $(|r|) = 0.54$.

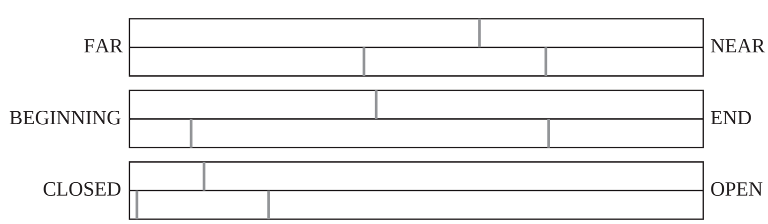


Figure 7. The proximity, span, and openness scales partitioned with the mean values obtained in both tasks in Study 1 (Table 1, Lines 17, 10, and 37).

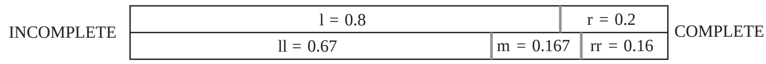


Figure 8. Partitioning of the incomplete–complete scale, with five of the measures given on Line 35 of Table 1.

To reveal the structure of these correlations, we used a principal component analysis (PCA, see Venables & Ripley, 2002, pp. 302–305). The first two PCAs account for 89% of the variance; adding a third accounts for 98% of the variance. The first two components are plotted in Figure 9. Its main features can be summarised as follows:

(1) Horizontal axis: m, lln, and rrn.
On the left, dimensions with large m ($m > 0.54$), i.e., a large fraction of each of these dimensions is neither one pole nor the other. For example: FULL–EMPTY ($m = 0.58$); TOP–BOTTOM ($m = 0.59$); and END–BEGINNING ($m = 0.62$).
On the right, dimensions with $m \approx 0$, i.e., only a minuscule fraction of each of these dimensions is neither one pole nor the other. As a result, lln (the fraction of l covered by ll) and rrn (the fraction of r covered by rr) are large: they nearly cover the dimension. For example: SYMMETRIC–ASYMMETRIC ($m = 0.14$); in FRONT OF–BEHIND ($m = 0.06$); and DIVERGENT–CONVERGENT ($m = 0.05$).
(2) Vertical axis: asym2
At the bottom, symmetric dimensions (low values of asym2). For example: RIGHT–LEFT ($asym2 = 0.04$); SUPPORTED–UNSUPPORTED ($asym2 = 0.05$); and SUNKEN–FLOATING ($asym2 = 0.10$).

TABLE 2
Nomenclature and symbols. By convention, $l \geq r$

Term	*Description*	*Symbol*	*Task*
γ-Fraction$_2$	Fraction of the dimension assigned to γ	l	1
$\bar{\gamma}$-Fraction$_2$	Fraction of the dimension assigned to $\bar{\gamma}$	r[a]	
Asymmetry$_2$	l–r	asym2	
Interfraction$_3$	Fraction of the dimension that is neither γ nor $\bar{\gamma}$	m	2
γ-Fraction$_3$	Γ on the γ side of m	ll	
$\bar{\gamma}$-Fraction$_3$	Γ on the $\bar{\gamma}$ side of m	rr[b]	
Relative γ-fraction$_3$	Proportion of l covered by ll	lln	
Relative $\bar{\gamma}$-fraction$_3$	Proportion of r covered by rr	rrn	
Asymmetry$_3$	|lln–rrn|	asym3[c]	

[a] $r = 1 - l$.
[b] $rr = 1 - ll - m$.
[c] Mean(asym3) = mean(lln)–mean(rrn).

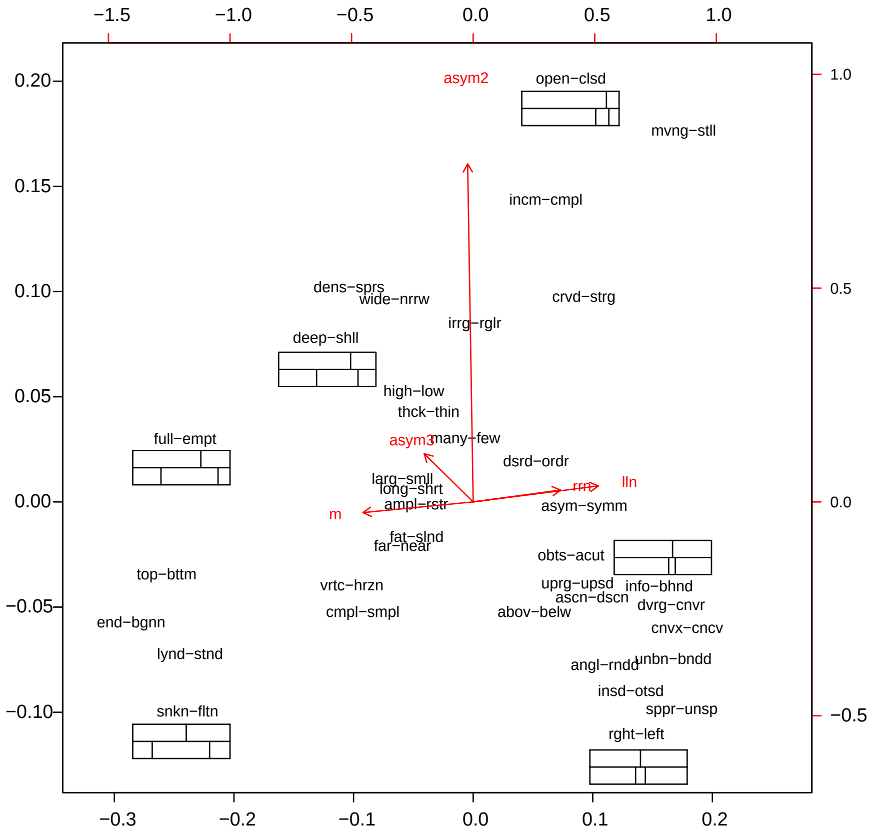


Figure 9. Study 1: biplot (Gabriel, 1971) of the first two principal components. Miniature versions of Figure 8 show that the difference between the number of Γ-bins for each pole (i.e., their asymmetry) grows along the ordinate, and that the sharpness of the transition between the γ and the $\overline{\gamma}$ (the extent of m) experiences grows along the abscissa. The biplot in this Figure and Figure 12 were rotated into Procrustean agreement (Dray, Chessel, & Thioulouse, 2003; Gabriel, 1971). [To view this figure in colour, please visit the online version of this Journal.]

On top, asymmetric dimensions (high values of asym2). For example: OPEN–CLOSED (asym2 = 0.73) and MOVING–STILL (asym2 = 0.68).

STUDY 2: THE TOPOLOGY OF DIMENSIONS

From Study 1 we obtained, for each dimension, an estimate of the proportion of the dimension covered by each pole and by neither. This study did not address the *topological* features of the dimensions that occur at the edges of these regions. Its data could not distinguish between *points* and *intervals*, between *open* intervals or rays and *closed* intervals or rays. We address the topology of poles and intermediates in turn.

The topology of poles

We can ask two questions: (1) Is a pole a point or an interval? (2) If it is an interval, is it open or closed?

(1) Is γ (or $\overline{\gamma}$) a point or an interval?

According to the results of Study 1, VERTICAL–HORIZONTAL and COMPLEX–SIMPLE are similar, because they are close in the space of Figure 9. That means that they are metrically similar. Topologically, however, they are different:

COMPLEX–SIMPLE. An object can be COMPLEX or SIMPLE in many different ways and to different degrees: *x* can be more COMPLEX or SIMPLE than *y*. Here both γ and $\overline{\gamma}$ define intervals.

VERTICAL–HORIZONTAL. In contrast, there is only one way for an object to be VERTICAL and only one way for an object to be HORIZONTAL. Here both γ and $\overline{\gamma}$ are points. In the language of Γ-*experience bins*, if γ reduces to a point, $N_\gamma = 1$. Study 1 provided no way to distinguish between small values of N_γ and $N_\gamma = 1$.

(2) If γ (or $\overline{\gamma}$) is an interval, is it open or closed?

Because OBTUSE–ACUTE and SYMMETRIC–ASYMMETRIC are close in the space of Figure 9, they are metrically similar. They can, however, be distinguished by their topology:

OBTUSE–ACUTE. An angle is most OBTUSE when it is as large as possible while being less than 360°, whereas an angle is most ACUTE when it is as small as possible while being greater than 0°. In topology this is called a *closed interval*. Consider the set of points *U* on a line between 0 and 1, and focus on the region around 0. If we think of the set *U* as containing 0 (i.e., $U \geq 0$) then *U* is closed on the left.

SYMMETRIC–ASYMMETRIC. If *U* does not contain 0 (i.e., $U > 0$) then *U* is open on the left: the distance of any point from the edge is always nonzero. Thus the upper edge of ASYMMETRIC is open: we can perceive a thing as being very ASYMMETRIC, but it could always be more ASYMMETRIC. Thus, technically speaking, it's an open ray.

Topology of intermediates

Here too we ask two questions: (1) Do intermediates exist? (2) If they exist, do they form an interval, or do they reduce to a point?

(1) Do intermediates exist?

Study 1 shows that both OBTUSE–ACUTE and SYMMETRIC–ASYMMETRIC have low proportions of m. However, there are no intermediates between SYMMETRIC and ASYMMETRIC: a figure is either one or the other; whereas there is an intermediate between OBTUSE–ACUTE: the 90° angle.

(2) If they exist, do they form an interval, or do they reduce to a point?

We have seen that the extension of m is very similar for ASCENDING–DESCENDING and UPRIGHT–UPSIDE DOWN. Topologically, however, they are different: there is only one intermediate between ASCENDING and DESCENDING (*to be level*), whereas the intermediates between UPRIGHT and UPSIDE DOWN form an interval.

Method

About 54 of the undergraduates from the preliminary study (forming 18 new groups of three) participated in two weekly sessions, each lasting 3 hours. The sessions took place during the weeks that followed Study 1.

To convey our topological concepts to the participants, we had to make them less abstract. To achieve this, we translated these terms into everyday language. This meant that in some cases we had to combine some topological distinctions into single terms. This was the case with the distinction between *ray* and *interval*. These were merged into a less technical term, *range*. We also did not use the distinctions between *closed* and *half-closed* intervals or between *open* and *half-open* intervals. Instead we asked about each pole whether it was *bounded* or *unbounded* at its extreme value. Figure 10 summarises the topological taxonomy as presented to the participants.

The 37 spatial dimensions were listed in a table. For each dimension, three metric characteristics—corresponding to l, r, and m in Study 1—were listed in three columns. They were labelled Pole A, intermediate, and Pole B. For each group of participants, the assignment of dimensions to rows and the right–left positions of the poles were randomised.

We asked the participants to indicate, for each dimension: (1) "Do the poles identify a unique point of experience or a range of experiences? If it is a range of experiences, is the range bounded or unbounded; that is, is there a well-defined experience which delimits the maximum possible degree of the property"? and

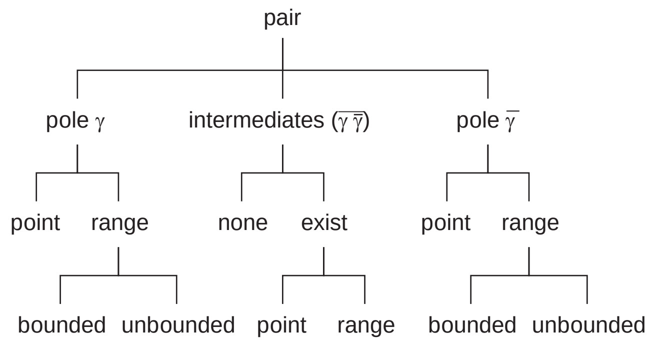


Figure 10. The topological structure of dimensions as conveyed to the participants.

(2) "Are there intermediate states (neither small, nor large)? If so, are there many of such states, or just one"? The instructions were given orally at the beginning of the session; they were also written at the top of the response sheet.

Results and discussion

We coded responses to γ and $\overline{\gamma}$ (the two poles) as P (point), B (bounded range), or U (unbounded range), and the responses to $\overline{\gamma\overline{\gamma}}$ (i.e., neither γ nor $\overline{\gamma}$) as N (none), P (point), or R (range). We then identified each response as an element of the Cartesian product of the three sets {P,B,U}, {N,P,R}, and {P,B,U}. From these we obtained nine-response types: P––; B––; U––; –N–; –P–; –R–; ––P; ––B; and ––U.

Contingency analysis

To examine the frequencies of responses, we analysed the three-way contingency table of the 3×3 possible pairings of responses to the two poles with the three types of responses to intermediates with the mosaic plot shown in Figure 11. Each cell is shaded so that it represents the magnitude of the Pearson residual for that cell i, $r_i^{(P)}$ (the standardised deviation of the observed frequency in cell i from expected frequency in that cell), which measures the departure of each cell from independence. The lightest shading is reserved for cells with values of $r_i^{(P)}$ between -2 and 2; in these the observed frequency does not depart significantly from the expected. The darkest-coloured cells deviate significantly ($\alpha \approx 0.0001$); those with a lighter shade deviate at $\alpha \approx 0.05$.

From this mosaic plot we learn that:

Symmetric structures are preferred. Of the seven topological types represented more frequently than expected (PNP, UNP, BPB, PPP, UPU, PRP, and URB), five are symmetric.

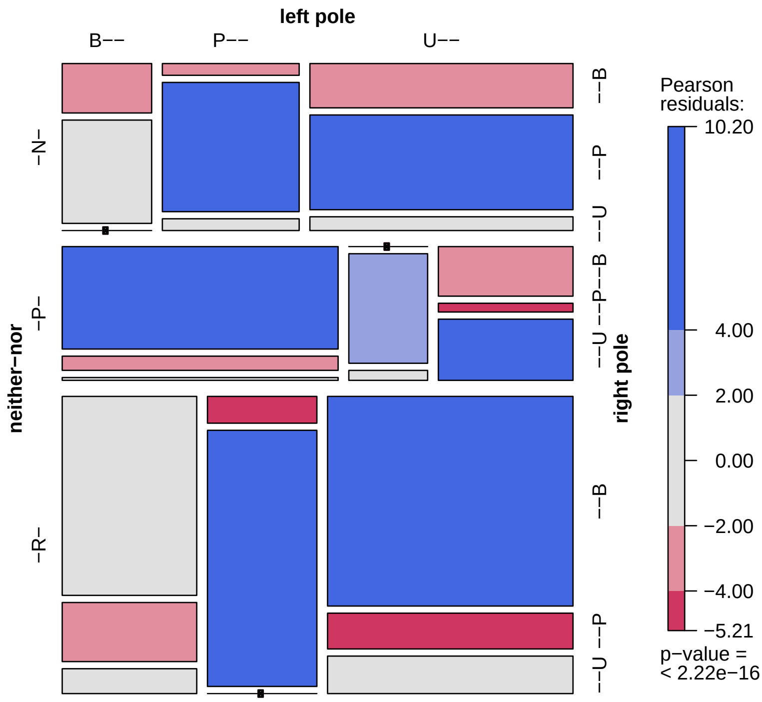


Figure 11. Study 2: a mosaic plot of the three-way contingency table of the 3×3 possible pairings of responses to the two poles with the three types of responses to the "neither–nor" question ($\overline{\gamma\gamma}$). Each of the 27 cells of this plot is proportional to the count of choices it represents. The table is stratified by the three types of $\overline{\gamma\gamma}$ responses, each represented by a block whose height is proportional to the count of the three $\overline{\gamma\gamma}$ responses. [To view this figure in colour, please visit the online version of this Journal.]

Most structures are either preferred or shunned. Only eight out the 27 cells fail to deviate significantly from expected (which is why the overall p-value is close to 0). We performed a PCA on the frequencies of the 37 pairs $\times$ 9 response types. Two, three, and four components accounted for 67%, 87%, and 95% of the variance, respectively. The two-dimensional solution is shown in Figure 12.

Rather than analyse the results of Study 2 separately, we found that analysing them together gets us to the important insights most effectively.

JOINT ANALYSIS OF THE TWO STUDIES

In order to compare the results of the two studies, we first rotate the biplots in Figures 9 and 12 into Procrustean agreement (i.e., the corresponding

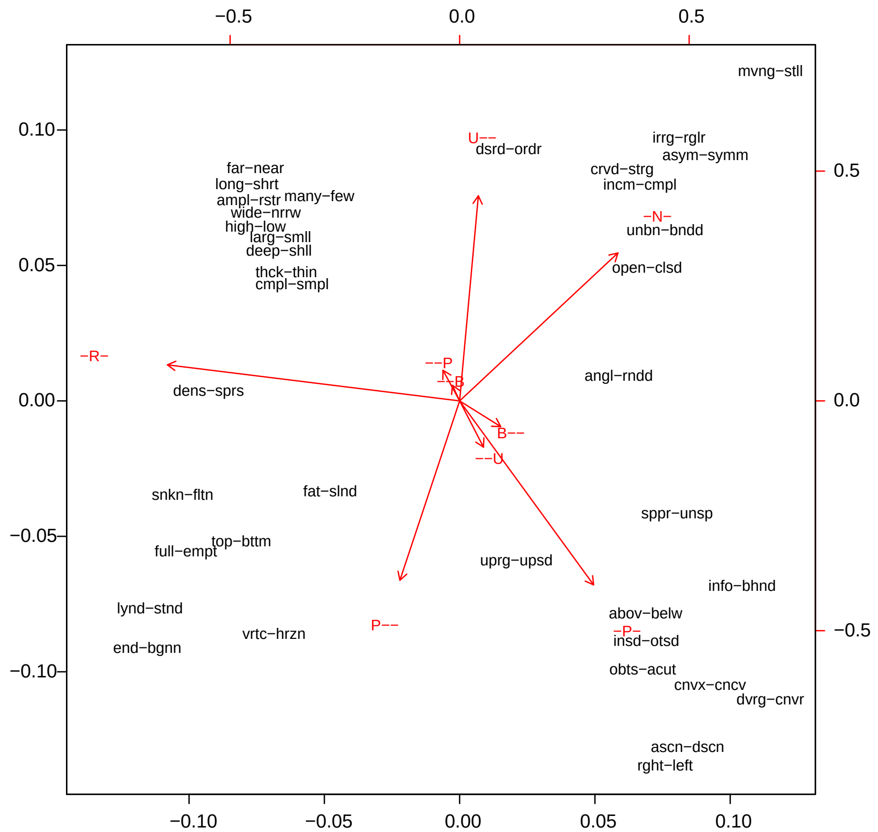


Figure 12. Study 2: biplot of the first two principal components. This biplot and Figure 9 have been rotated into Procrustean agreement.

matrices are rotated to maximum similarity by minimising the sum of the squared differences between them, by the method proposed by Dray et al., 2003, implemented in the *R* package ade4; see Dray & Dufour, 2007).

Movement of dimensions between the studies

By determining which points moved the most between the two studies, we can better understand the similarities and differences between the results of the two studies. Figure 13 shows these changes. (The horizontal and vertical bars on the upper left side of the plot represent the mean absolute change in the x and y directions.)

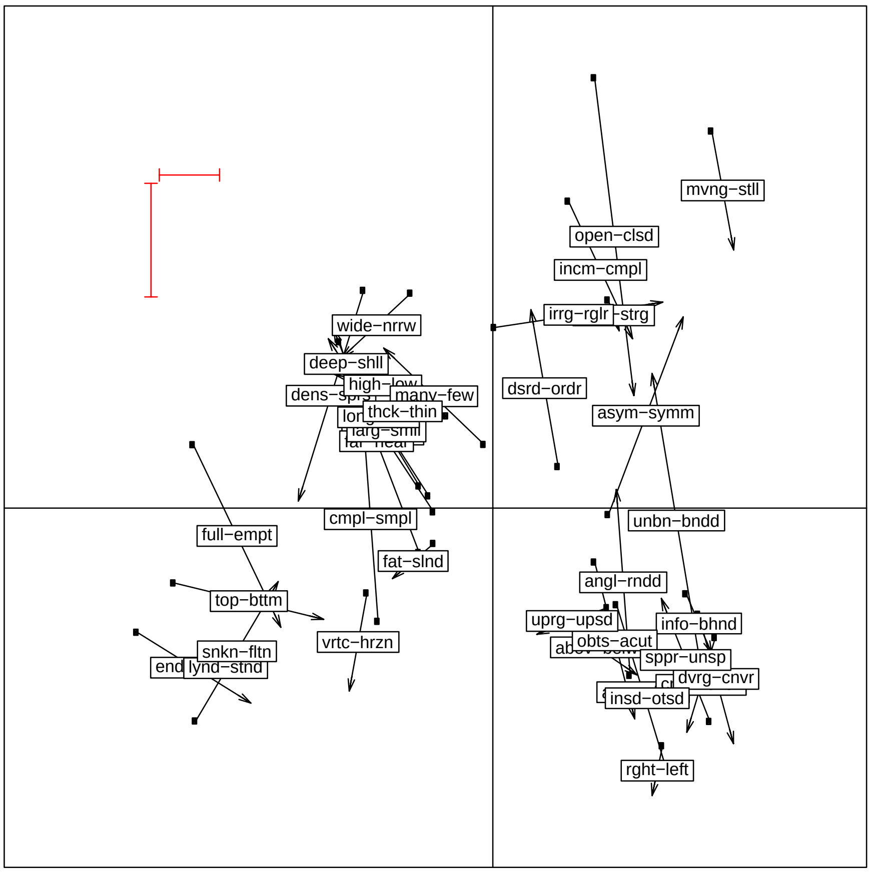


Figure 13. Differences between the biplots for the two studies. The horizontal and vertical bars on the upper left side of the plot represent the average absolute amount of shift in the two directions.

Changes between Studies 1 and 2 are larger in the y direction

We observe that: (1) the mean change in the x direction is $\Delta x = 0.36$, whereas in the y direction, it is almost twice as large: $\Delta y = 0.68$ ($\Delta y - \Delta x = 0.32$, 95% CI = [0.13, 0.51] by one-sample t-test, which is equivalent to a two-sided test of the null hypothesis that $\Delta y = \Delta x$ with $\alpha = 0.025$); (2) if we consider only the 11 largest changes, the difference between the amount of change in the two directions is even larger ($\Delta y - \Delta x = 0.74$, 95% CI = [0.33, 1.15], one-sample t-test); and (3) only three dimensions moved further along x than y.

Why did the topological information not cause large horizontal motions? Because the horizontal axis in Study 1 represents, for the most part, the width of m, the proportion of intermediates. On the left of the space, m is large, on its right, m is small. Since only a metric change can transform a small quantity into a large one, or vice-versa, adding topological information can have little effect.

What the topological information adds to the metric information?

Table 3 lists the five largest vertical changes. To see the cause of these changes, we need to compare the location of the dimension in the metric space of Figure 9, which is, by and large a function of *m* and asym2, which are given in the second and third columns of the table. These values would place COMPLEX–SIMPLE in the lower left quadrant of Figure 12, a region of dimensions whose left pole is a point (P—). Since this dimension is of topological type U—, it had to move upward. The same reasoning applies to the remaining four dimensions.

The joint space

Having understood the commonalities and the differences between the results of the two studies, we computed a joint space, to capture the metric and topological results in one representation (Figure 14). We performed a co-inertia analysis (CIA) on these two sets of results. This is an extension of multidimensional ordination methods such as PCA or correspondence analysis. It summarises data by searching for one axis for each data-set with maximum covariance, such that they will: (1) be highly correlated and (2) explain a large percentage of the variance (Culhane, Perriere, & Higgins, 2003; Culhane & Thioulouse, 2006). The results are shown in Figure 15. In this map, the first joint (co-inertia) axis is strongly linked to both axes of the PCA of Study 1, whereas the second joint axis is related to the vertical axis of the PCA of Study 2. Thus, by rotating the biplots of the two studies into Procrustean agreement, we have shown that the topological task of Study 2 refines the metric data of Study 1. It does so by distinguishing between: (1) point poles and unbounded poles and (2) point intermediates and no intermediates.

TABLE 3
The five largest vertical changes between the two studies

Dimension	m	asym2	*Placed by* asym2	*Moves toward*
COMPLEX–SIMPLE	0.39	0.14	P––	U––
DENSE–SPARSE	0.40	0.40	U––	P––
FAR–NEAR	0.31	0.35	U––	P––
UNBOUNDED–BOUNDED	0.05	0.04	–P–	–N–
OPEN–CLOSED	0.14	0.16	–N–	–P–

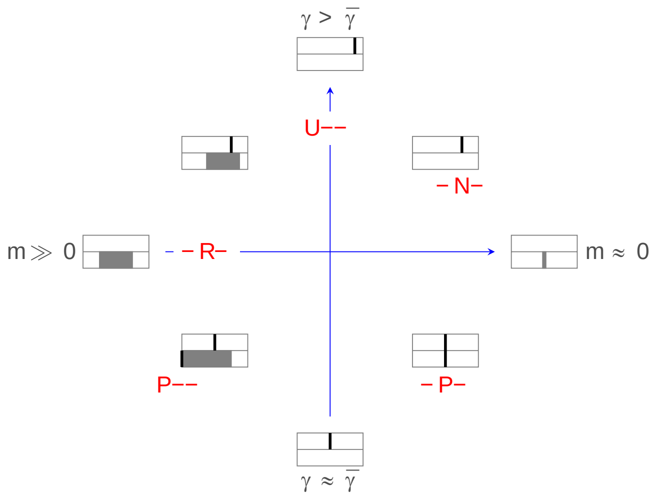


Figure 14. The major topological features of opposites (in bold characters) superimposed on their characteristic metric features.

Clustering

As a final step we clustered the CIA of the joint data to discover whether we could propose a taxonomy of dimensions and their poles. In order to determine the optimal number of clusters, we used the PAM (Partitioning Around Medoids) partition method, which searches for a predetermined number (say k) of representative dimensions, called *medoids* (Kaufman & Rousseeuw, 1990; Struyf, Hubert, & Rousseeuw, 1997). PAM finds k medoids for which the total similarity of all dimensions to their nearest medoid is minimal. Medoids are representative objects of a data-set whose average dissimilarity to all the objects in the cluster is minimal. They are conceptually similar to centroids, with the exception that a medoid is always a member of the data-set. In order to determine k, we used Kaufman and Rousseeuw's (1990) *silhouette plot*, in which each cluster is represented by an ordered set of bars of one colour, a silhouette. Each bar can range from -1 to 1. When a bar's height approaches 1, then the corresponding pair lies well within that cluster; when it is close to 0, it is intermediate between two clusters; and when it approaches -1, it is poorly classified (i.e., it belongs to a different cluster).

Figure 16 shows the silhouette plot for the results of our CIA, with $k = 4$. Only five of the 37 dimensions have silhouette values of $s(i)$, below 0.5. The quality of the clustering is given by the average of the $s(i)$ values, which in this case is 0.67. Because other values of k produce lower average $s(i)$ values, 0.67 is also the *silhouette coefficient*, which tells us how much clustering structure is present in the data (0.25 is considered no structure).

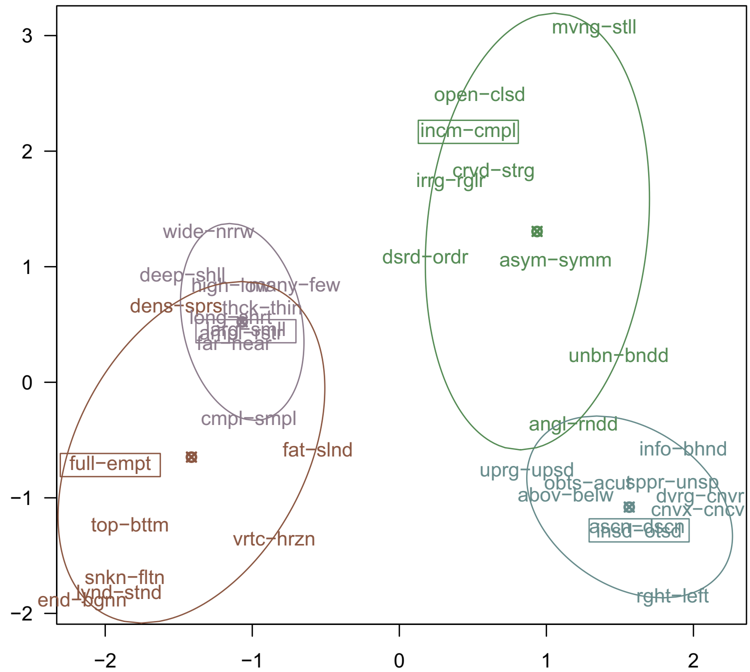


Figure 15. Co-inertia (CIA) representation of the results of both studies. Superimposed on this plot are the four clusters obtained by the PAM partition method. The medoid pair-name of each cluster is framed. Each cluster is fitted with an ellipse of minimal area such that all of the pairs lie on or inside its boundary. The names of the pairs in each cluster are distinguished by having a different font. The centres of the ellipses are marked with the symbol ⊗. [To view this figure in colour, please visit the online version of this Journal.]

The four medoids identified by PAM were INSIDE–OUTSIDE, LARGE–SMALL, INCOMPLETE–COMPLETE, and FULL–EMPTY (each has either the largest or the second largest silhouette value in its cluster). They are framed on the CIA representation of the two studies (Figure 15). The boundary of each cluster is shown as an ellipse of minimal area such that all of the pole pairs in a cluster lie on or inside this boundary. The centres of these ellipses are marked with the symbol ⊗ (Pison, Struyf, & Rousseeuw, 1999). Table 4 summarises the clusters.

GENERAL DISCUSSION

We have shown that dimensions and opposites can be exhaustively described in metric and topological terms. A small number of principal components

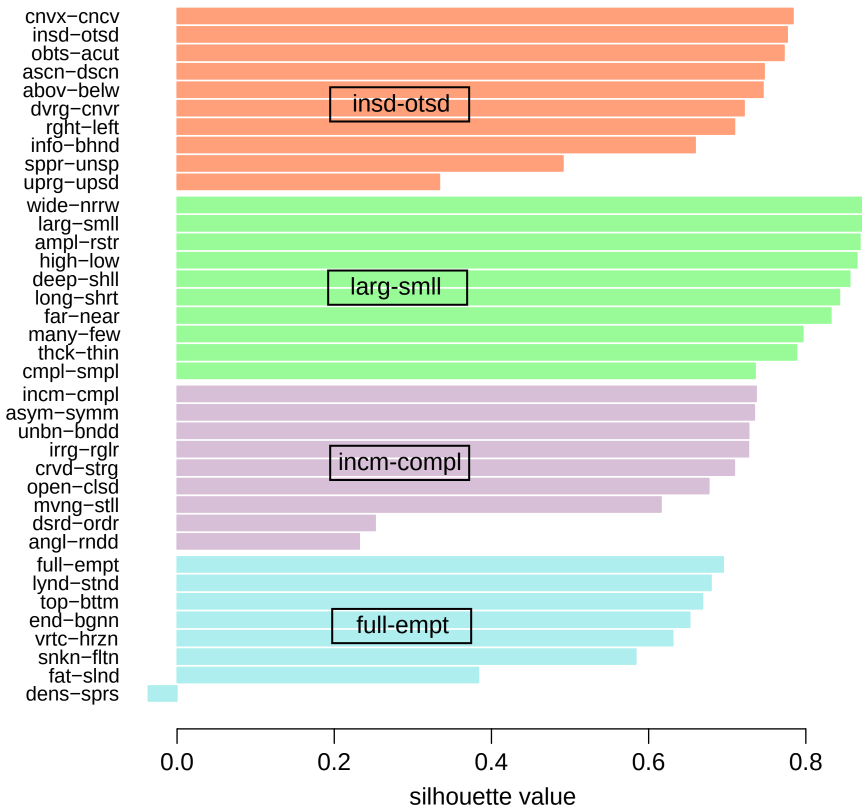


Figure 16. Silhouette plot for the joint data with four clusters. The framed pair names are the cluster medoids. [To view this figure in colour, please visit the online version of this Journal.]

TABLE 4
The four clusters of Figure 15, defined by metric properties and refined by topological properties, account for 78% of the dimensions

Cluster	*Medoid*	asym2	m ≈	*Topology*	*Percentage (%) ≈*
I	INCOMPLETE–COMPLETE	Strong	0	UNP[a], UNB[b]	14
II	LARGE–SMALL	Moderate	1/3	URB[a]	19
III	FULL–EMPTY	Moderate	2/3	PRP[a], BRP[b], BRB	24
IV	INSIDE–OUTSIDE	Minimal	0	BPB[a], PNP[a], UPU[a]	21
					78

[a]Frequency significantly above expected in the contingency table summarised in Figure 11.
[b]Frequency below expected.

account for a large proportion of the metric variation (here three components accounted for 98% of the metric variation) and the topological variation (four principal components accounted for 95% of the topological variation).

To simplify our presentation of the data, we represented the metric data with two principal components, which account for 89% of the metric variation, and the topological data with two principal components, which account for 67% of the topological variation. We concluded that to characterise a dimension and its poles, we need two types of information, metric and topological. We require:

Metric information about the:

- asymmetry of the poles, asym2 and
- width of the "neither–nor" region, m.

Topological information about:

- each pole
  - *bounded* (B),
  - a *point* (P), and
  - *unbounded* (U); and
- the "neither–nor" region:
  - *nonexistent* (N),
  - a *point* (P), and
  - an *interval* (range, R).

We also produced two progressively more intuitive—and hence less accurate—representations of the different types of dimensions and opposites:

- a joint two-dimensional space (Figure 15) and
- a four-fold clustering of opposites and dimensions (Table 4).

The identification of different structures of opposites, which has come out from our psychophysical tasks, provides a new experimental classification of opposites based on the perceptual organisation of the variations of a property in between two opposite extremes which is worth to be compared with other classifications of opposites developed in linguistic literature, based on semantic or pragmatic considerations (Cruse, 1986; Jones, 2002; Kennedy & McNally, 2005; Lyons, 1977).

Before we further discuss our results, we address three methodological issues:

Our method of data collection

One might be concerned with the validity of our method for three reasons:

(1) working in groups might produce idiosyncratic results because
  (a) all the groups worked in the same setting,
  (b) of some subtle group decision-making effect, and
  (c) of contamination between the groups;
(2) having done Study 1 might have affected the groups' judgements in Study 2 (even though the students belonged to different groups in the two studies); and
(3) the spatial sophistication of the participants (they were students of design).

To allay these concerns, one of us (Ivana Bianchi) replicated Study 2 with a different population (students of philosophy) in a different setting (University of Macerata). These participants did not previously participate in Study 1. As the data show (summarised in the Appendix 1), the results are by and large the same as the results reported here for Study 2.

Our ability to capture ambiguities

Most of our participants described INSIDE–OUTSIDE as PPP (as Ogden, 1932/1967, had done, quoted in the Introduction): the boundary between INSIDE and OUTSIDE is a point and if one has crossed the threshold from OUTSIDE, one *is* inside, regardless of whether one has gone deeply inside or stayed near the threshold. Some of our participants, however, described it as BPU, presumably because you can be far inside or far outside an enclosure, or just inside or just outside its threshold. Likewise, most of the participants characterised SUPPORTED–UNSUPPORTED as PNP: there is no intermediate state between being supported and not; each of the poles is a state that admits no degrees. However, some of them thought that you could be nearly supported or far from being supported, and chose PNU. Finally, the most common choice for ABOVE–BELOW was UPU because a thing can be far above or below another; and yet some treated the pair as analogous to INSIDE–OUTSIDE, and called it PPP. Unfortunately, the number of participants in our studies precludes us from investigating these ambiguities. Had we a much larger number of participants, we would have been able to take these differences into account, and might have obtained crisper results.

The generalisability of our methods

Our methods will allow us to answer two further questions:

(1) To what extent would maps generated from data obtained in other languages be analogous to the one we obtained here? What are the criteria for claiming that the maps are similar enough to warrant the claim of cross-linguistic generalisability? Such generalisability would imply that opposites transcend any particular language. This would redouble the efforts to understand their origin.
(2) To what extent would maps generated from data obtained with nonspatial dimensions, such as BENIGN–MALIGNANT, FOREIGN–LOCAL, or DEAD–ALIVE conform to the maps we obtained here? If they did, this would redouble the efforts to understand how spatial (and bodily) experiences might undergird cognition.

Although the readers of this article may suspect that some of the pairs used in this study might not appear in a list generated by native English speakers (e.g., ample–restricted), by and large our results are consistent with languages other than Italian. We have asked native speakers of Chinese, English, French, German, Hebrew, and Spanish whether they found any of our results inconsistent with their language. The unanimous answer was no.

Indeed considerable evidence suggests that languages are more united by their spatial semantics (Barsalou, 1999; Glenberg & Robertson, 2000; Logan & Saddler, 1996; Regier, 1996) than they are divided by them (Bowerman, 1996; Levinson, 1996). Perhaps this is because languages and visual processing of scenes have been found to match up, suggesting that "it should be possible to offer more precise definitions of [spatial terms] as opposed to many other expressions because the definitions can be grounded on how we perceive the worlds themselves" (Coventry & Garrod, 2004, p. 5).

Such a linkage between language and sensory process may be responsible for a cross-linguistic consistency between Swedish and Russian temperature adjectives. According to Koptjevskaja-Tamm and Rakhilina (2006), such adjectives are:

> . . . rooted in human experience of temperature. Language on the whole, and the linguistic domain of temperature in particular, is . . . governed by anthropocentricity. First, temperature attributes are chosen relatively to . . . parameters, that are . . . salient for humans [but] . . . have only very approximate physical correlates . . . Second, [whether] temperature properties [of physical objects] . . . are . . . worth mentioning . . . depends on [their] function . . . in . . . human life. (p. 267)

This consistency would be expected from the view of Pecher and Zwaan (2005):

> Rather than being merely input and output devices, perception and action are considered central to higher cognition ... *cognitive structures develop from perception and action*. (pp. 1, 2, emphasis ours)

In particular, dimensions and opposites probably have their roots in prelinguistic cognition, and may therefore transcend any particular language. For instance, infants understand spatial dimensions and opposites, such as INSIDE–OUTSIDE, SUPPORTED–UNSUPPORTED, HORIZONTAL–VERTICAL, TIGHT–LOOSE, OPENING–CLOSING, LEFT–RIGHT, and UP–DOWN before they acquire spatial language (Casasola, 2008; Casasola, Cohen, & Chiarello, 2003; Hespos & Spelke, 2004; McDonough, Choi, & Mandler, 2003; Quinn & Bhatt, 2005; Quinn, Cummins, Kase, Martin, & Weisman, 1996). This is probably also true of nonvisual sensory dimensions, such as HOT–COLD.

Thus, the current literature supports the views that two of us developed after these data were collected (Bianchi & Savardi, 2006, 2008a,b; Savardi & Bianchi, 2009): namely, that we spontaneously perceive many nonlinguistic forms of spatial contrariety. They studied a large sample of simple geometric figures, body postures, and gestures; all of them have contraries. These results support the hypothesis that the concept of contrariety (which also manifests itself linguistically) is grounded in nonlinguistic perceived opposition.

Finally, the psychological reality of the structures we have uncovered is no different than other lawful regularities discovered in psychology, such as Stevens's power law, or the colour circle obtained by Shepard (1962) using multidimensional scaling. What Stevens and Shepard obtained are laws, not theories. They also resemble our results because the mechanisms that underlie them are inaccessible to introspection. So, as it stands, we see our description(s) of dimensions and their poles as a collection of lawful regularities in search of a theory.

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REFERENCES

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–609.

Bianchi, I., & Savardi, U. (2006). The opposite of a figure. *Gestalt Theory*, *4*, 354–374.

Bianchi, I., & Savardi, U. (2008a). *The perception of contraries*. Roma: Aracne.

Bianchi, I., & Savardi, U. (2008b). The relationship perceived between the real body and the mirror image. *Perception*, *5*, 666–687.

Bowerman, M. (1996). Learning how to structure space for language: A cross-linguistic perspective. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 385–436). Cambridge, MA: MIT Press.

Bozzi, P. (1989). *Fenomenologia sperimentale* [Experimental phenomenology]. Bologna: II Mulino.

Breivik, E. K., Bjornsson, G. A., & Skovlund, E. (2000). A comparison of pain rating scales by sampling from clinical trial data. *Clinical Journal of Pain*, *16*(1), 22–28.

Casasola, M. (2008). The development of infants' spatial categories. *Current Directions in Psychological Science*, *17*, 21–25.

Casasola, M., Cohen, L. B., & Chiarello, E. (2003). Six-month-old infants' categorization of containment spatial relations. *Child Development*, *74*, 679–693.

Cass, J., Stuit, S., Bex, P., & Alais, D. (2009). Orientation bandwidths are invariant across spatiotemporal frequency after isotropic components are removed. *Journal of Vision*, *9*, 1–14. Retrieved from http://www.journalofvision.org/9/12/17

Clark, A. (1993). *Sensory qualities*. Oxford, UK: Clarendon Press.

Coventry, K. R., & Garrod, S. C. (2004). *Saying, seeing, and acting: The psychological semantics of spatial prepositions*. Hove, UK: Psychology Press.

Cruse, D. A. (1986). *Lexical semantics*. Cambridge, UK: Cambridge University Press.

Cruse, D. A., & Togia, P. (1995). Towards a cognitive model of antonymy. *Lexicology*, *1*, 113–141.

Culhane, A., Perriere, G., & Higgins, D. (2003). Cross-platform comparison and visualisation of gene expression data using co-inertia analysis. *BMC Bioinformatics*, 4:59.

Culhane, A. C., & Thioulouse, J. (2006). A multivariate approach to integrating datasets using made4 and ade4. *Rnews*, *6*, 54–58.

De Dreu, C. K. W., Nijstad, B. A., & van Knippenberg, D. (2008). Motivated information processing in group judgment and decision making. *Personality and Social Psychology Review*, *12*(1), 22–49.

Dray, S., Chessel, D., & Thioulouse, J. (2003). Procustean co-inertia analysis for the linking of multivariate datasets. *Ecoscience*, *10*, 110–119.

Dray, S., & Dufour, A.-B. (2007). The ade4 package: Implementing the duality diagram for ecologists. *Journal of Statistical Software*, *22*, 1–20.

Duncker, K. (1945). On problem-solving. *Psychological Monographs*, *58*, (Whole No. 270).

Fox, J. (2002). *An R and S-PLUS companion to applied regression*. Thousand Oaks, CA: Sage.

Freedman, D., & Diaconis, P. (1981). On the histogram as a density estimator. *Zeitschrift für Wahrscheinlichkeitstheorie und Verwandte Gebiete*, *57*, 453–476.

Fung, Y.-L. (1948/1976). *A short history of Chinese philosophy: A systematic account of Chinese thought from its origins to the present day* (D. Bodde, Ed.). New York, NY: The Free Press.

Gabriel, K. R. (1971). The biplot graphical display of matrices with applications to principal component analysis. *Biometrika*, *58*, 453–467.

Gardenfors, P. (2000). *Conceptual spaces: The geometry of thought*. Cambidge, MA: MIT Press.

Gardenfors, P. (2007). Representing actions and functional properties in conceptual spaces. In T. Ziemke, J. Zlatev, & R. M. Frank (Eds.), *Body, language, and mind: Embodiment* (pp. 167–196). Berlin: Walter de Gruyter.

Givon, M. M., & Shapira, Z. (1984). Response to rating scales: A theoretical model and its application to the number of categories problem. *Journal of Marketing Research*, *21*, 410–419.

Glenberg, A. M., & Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory & Language*, *43*, 379–401.

Hecht, S., Shlaer, S., & Pirenne, M. H. (1941). Energy at the threshold of vision. *Science*, *93*, 585–587.

Hespos, S. J., & Spelke, E. S. (2004). Conceptual precursors to language. *Nature*, *430*(6998), 453–456.

Hinsz, V. B., Tindale, R. S., & Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin*, *121*(1), 43–64.

Ihaka, R., & Gentleman, R. (1996). R: A language for data analysis and graphics. *Journal of Computational and Graphical Statistics*, *5*, 299–314.

Jones, S. (2002). *Antonymy: A corpus-based approach*. London, UK: Routledge.

Kaufman, L., & Rousseeuw, P. (1990). *Finding groups in data: An introduction to cluster analysis*. New York, NY: Wiley.

Kennedy, C. (2007). Vagueness and grammar: The semantics of relative and absolute gradable adjectives. *Linguistics and Philosophy*, *30*, 1–45.

Kennedy, C., & McNally, L. (2005). Scale structure, degree modification, and the semantics of gradable predicates. *Language*, *81*(2), 345–381.

Kocher, M. G., & Sutter, M. (2005). The decision maker matters: Individual versus group behaviour in experimental beauty-contest games. *Economic Journal*, *115*(500), 200–223.

Koptjevskaja-Tamm, M., & Rakhilina, E. V. (2006). "Some like it hot": On the semantics of temperature adjectives in Russian and Swedish. *Sprachtypologie und Universalienforschung*, *59*, 253–269.

Kubovy, M. (1999). Gestalt psychology. In R. A. Wilson & F. C. Keil (Eds.), *The MIT encyclopedia of the cognitive sciences* (pp. 346–349). Cambridge, MA: MIT Press.

Kubovy, M. (2003). Phenomenology, psychological. In L. Nadel (Ed.), *Encyclopedia of cognitive science* (pp. 579–586). Basingstoke, UK: Nature Publishing Group.

Kubovy, M., & Gepshtein, S. (2003). Grouping in space and in space-time: An exercise in phenomenological psychophysics. In R. Kimchi, M. Behrmann, & C. R. Olson (Eds.), *Perceptual organization in vision: Behavioral and neural perspectives* (pp. 45–86). Mahwah, NJ: Erlbaum.

Landau, B., & Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral and Brain Sciences*, *16*, 217–265.

Levinson, S. C. (1996). Relativity in spatial conception and description. In J. J. Gumperz & S. C. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 177–202). Cambridge, UK: Cambridge University Press.

Liang, D. W., Moreland, R., & Argote, L. (1995). Group versus individual training and group performance: The mediating role of transactive memory. *Personality and Social Psychology Bulletin*, *21*(4), 384–393.

Lloyd, G. E. R. (1966/1992). *Polarity and analogy: Two type of argumentation in early Greek thought*. Indianapolis, IN: Hackett.

Logan, G. D., & Saddler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel, & M. Garrett (Eds.), *Language and space* (pp. 493–529). Cambridge, MA: MIT Press.

Lyons, J. (1977). *Semantics*. Cambridge, UK: Cambridge University Press.

Mair, P., & Hatzinger, R. (2007). Cml based estimation of extended rasch models with the eRm package in r. *Psychology Science*, *49*, 26–43.

McDonough, L., Choi, S., & Mandler, J. M. (2003). Understanding spatial relations: Flexible infants, lexical adults. *Cognitive Psychology*, *46*, 229–259.

Ogden, C. K. (1967). *Opposition: A linguistic and psychological analysis* (Reprint ed.). Bloomington, IN: Indiana University Press. (Original work published 1932)

Paradis, C., & Willners, C. (2006). Antonymy and negation—the boundedness hypothesis. *Journal of Pragmatics*, *38*, 1051–1080.

Pecher, D., & Zwaan, R. A. (Eds.). (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge, UK: Cambridge University Press.

Pison, G., Struyf, A., & Rousseeuw, P. J. (1999). Displaying a clustering with CLUSPLOT. *Computational Statistics and Data Analysis*, *30*, 381–392.

Quinn, P. C., & Bhatt, R. S. (2005). Good continuation affects discrimination of visual pattern information in young infants. *Perception & Psychophysics*, *67*, 1171–1176.

Quinn, P. C., Cummins, M., Kase, J., Martin, E., & Weisman, S. (1996). Development of categorical representations for above and below spatial relations in 3- to 7-month-old infants. *Developmental Psychology*, *32*, 942–950.

R Development Core Team. (2010). *R: A language and environment for statistical computing*. Vienna: Author.

Regier, T. (1996). *The human semantic potential: Spatial language and constrained connectionism*. Cambridge, MA: MIT Press.

Rosnow, R. L. (2000). Semantic differential. In A. E. Kazdin (Ed.), *Encyclopedia of psychology* (Vol. 7, pp. 224–225). Washington, DC and Oxford: American Psychological Association and Oxford University Press.

Savardi, U., & Bianchi, I. (2000). *L'identità dei contrari [The identity of opposition]*. Verona: Cierre.

Savardi, U., & Bianchi, I. (2009). The spatial path to contrariety. In U. Savardi (Ed.), *The perception and cognition of contraries* (pp. 63–92). Milan: McGraw-Hill.

Shepard, R. (1962). The analysis of proximities: Multidimensional scaling with an unknown distance function. II. *Psychometrika*, *27*(3), 219–246.

Smith, C. M., Bushouse, E., & Lord, J. (2010). Individual and group performance on insight problems: The effects of experimentally induced fixation. *Group Processes Intergroup Relations*, *13*(1), 91–99.

Struyf, A., Hubert, M., & Rousseeuw, P. J. (1997). Integrating robust clustering techniques in s-plus. *Computational Statistics & Data Analysis*, *26*, 17–37.

Talmy, L. (1983). How language structures space. In H. Pick & L. Acredolo (Eds.), *Spatial orientation: Theory, research, application* (pp. 225–282). New York, NY: Plenum Press.

Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). New York: Springer.

Weisstein, E. W. (2008). *Interval*. From MathWorld—A Wolfram Web Resource. Retrieved from http://www.mathworld.wolfram.com/Interval.html

Wheelan, S. A. (2009). Group size, group development, and group productivity. *Small Group Research*, *40*(2), 247–262.

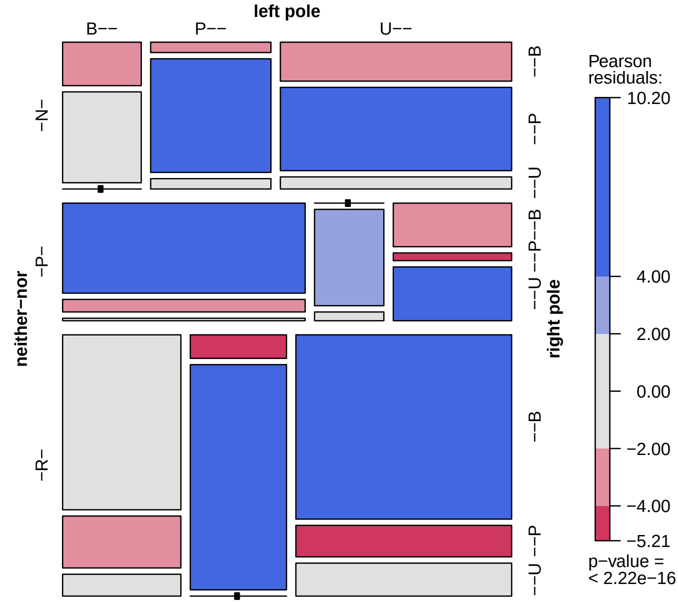
Willners, C., & Paradis, C. (2006). Antonymy and negation: The boundedness hypothesis. *Journal of Pragmatics*, *38*, 1051–1080.

APPENDIX 1. A REPLICATION OF STUDY 2

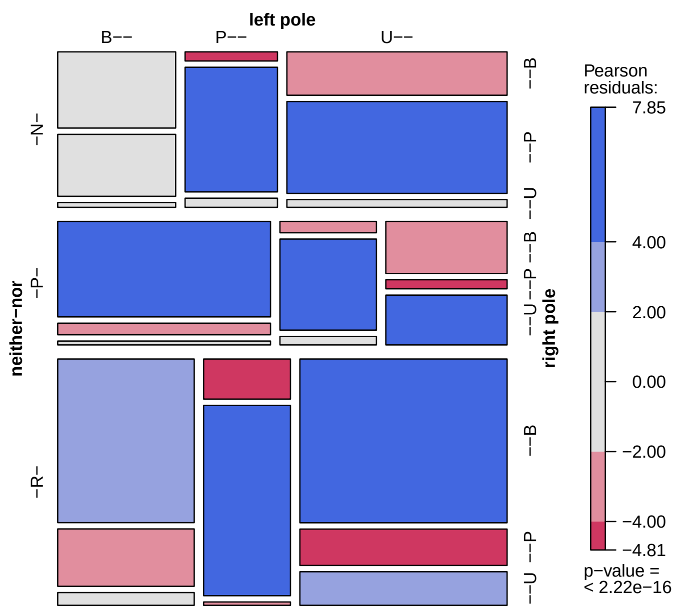
We wish to show: (1) that the use of the same participants in Study 2 as in Study 1 did not have an effect on the results of Study 2 and (2) that the results are replicable with a different sample of participants.

To that end, one of us (Ivana Bianchi) replicated Study 2 at the University of Macerata with 58 philosophy students. They were new to this sort of study. They formed 18 groups of three and two groups of two.

We analysed the data as we did for Study 2. Figure A1 shows that the pattern of response frequencies was the same for the original study and the replication, and Figure A2 shows that the structure that emerged from the PCA was also very much the same.

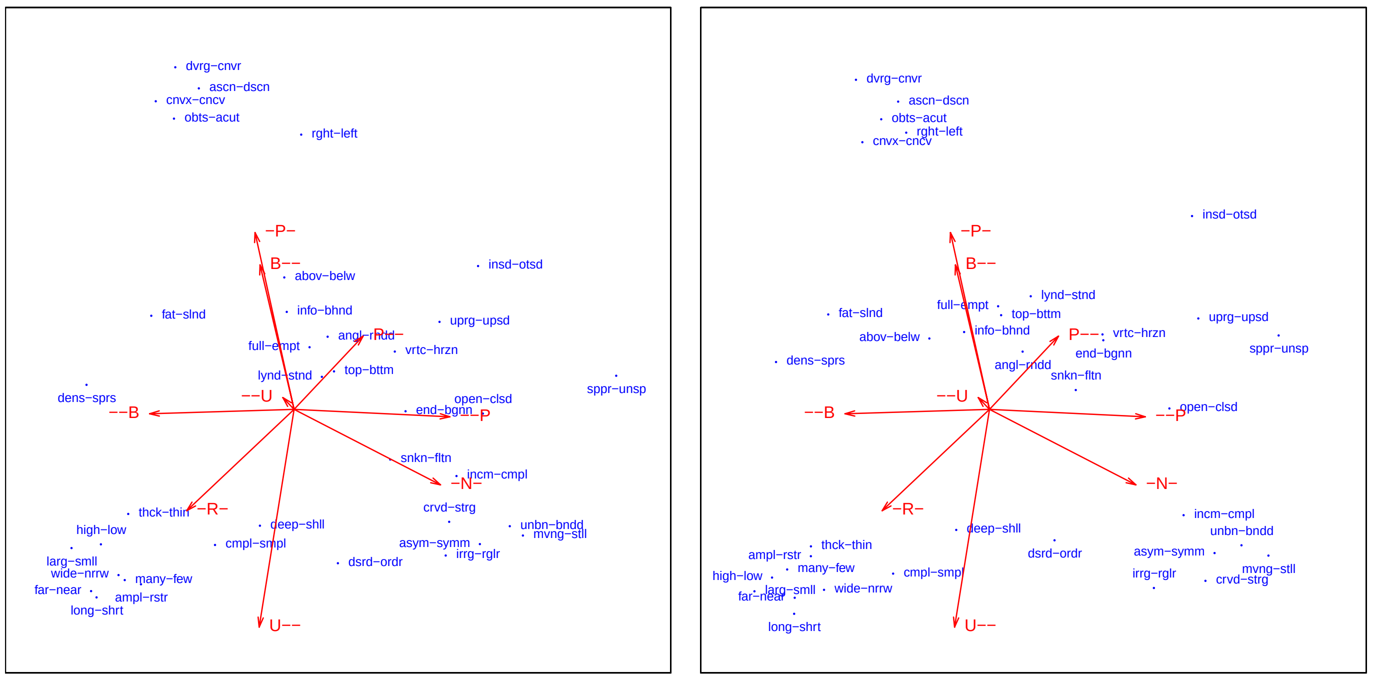


(a) Original study



(b) Replication

Figure A1. The mosaic plot shown in Figure 11 compared to the one for the replication study. [To view this figure in colour, please visit the online version of this Journal.]



(a) Original Study 2 (unrotated version of Figure 12)

(b) Replication of Study 2

Figure A2. Biplots of the first two principal components. [To view this figure in colour, please visit the online version of this Journal.]