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The opposite of a transformation process. An exploration based on diagrams

Elena Capitani[a], Erika Branchini[b], Roberto Burro[b], Ugo Savardi[b] and Ivana Bianchi[c]

[a]Department of Education, Cultural heritage and Tourism, University of Macerata (Italy) Macerata, Italy; [b]Department of Human Sciences, University of Verona, Verona, Italy; [c]Department of Humanities, University of Macerata, Macerata, Italy

ABSTRACT

We presented participants with simple diagrams representing a transformation from x to y, and asked them to draw what they considered to be the opposite process/es. The focus of the study was on the participants' naïve idea of opposites and on whether asking them to write a verbal description of the stimulus prior to the task (implying more conscious cognitive processing) would affect their responses.

A simple reversal of x and y was the first solution offered. However, the participants who performed the initial verbal description also thought of a second option, where x and y were modified but not reversed. Conversely, in cases where the participants did not give a prior written description, the two most frequent response patterns always implied a reversal of the initial order of x and y. The results are discussed in relation to previous literature on the naïve idea of opposites and on the subject of antithetical reasoning. Further issues to be investigated are also suggested.

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opposites; transformation processes; antithetical reasoning; relational reasoning; relational thinking; visual opposition

Introduction

The ability to identify or derive a relation of direct opposition (antithetical reasoning) is a fundamental cognitive skill on various levels. The term antithesis indicates a relationship between two mental representations which involves direct opposition (Kreezer & Dallenbach, 1929). It is fundamental to the organisation of human language and thought (De Saussure, 2011; Fellbaum, 1998; Jones et al., 2012; Kjeldergaard & Higa, 1962; Marková, 1987; Murphy, 2003). The ability to detect direct opposition is implied in the conceptual changes which people make when doing reasoning tasks (Bianchi et al., 2020; Branchini et al., 2015; Branchini et al., 2016; Broughton & Sinatra, 2010; Gale & Ball, 2002), and it also underlies the understanding of various widely used types of figurative language based on contrast, such as humour and irony (e.g. Calmus & Caillies, 2014; Canestrari et al., 2018; Canestrari & Bianchi, 2018; Colston & O'Brien, 2000a, 2000b; Giora et al., 2014; Hull et al., 2016). Reasoning with reference to antithetical relations has been linked to academic success, from kindergarten to higher education (Baker et al., 2010; Broughton & Sinatra, 2010).

This paper focuses on antithesis when applied to *two processes*. It has already been claimed that the ability to recognise an antithetical relation between two processes plays a key role in argumentation and persuasion (Chinn & Anderson, 1998; Kuhn & Udell, 2007), as well as in empirical scientific research, for example, showing that a decrease rather than an increase in the development of two different bacterial populations (after inoculation with the same gene) indicates the critical role of the modified variable (Dumas, 2017). How people conceptualise the opposite of a given process beyond the contexts mentioned thus far (e.g. argumentation, persuasion and scientific discovery) is still a subject for empirical research. Given the current general debate on the distinction between automatic versus conscious reasoning processes (Evans & Stanovich, 2013a, 2013b), it seemed relevant in this case to contextualise our investigation into antithesis which applies to two processes within this framework. This is reflected in the use of two different experimental conditions, as will be seen in the description of the study.

CONTACT Ivana Bianchi ivana.bianchi@unimc.it Department of Humanities, University of Macerata, via Garibaldi, 20, 62100, Macerata, Italy

An essential contribution to our understanding of antithetical reasoning was developed in the course of a decade by Alexander and colleagues in relation to a number of domains (e.g. Dumas et al., 2013, 2014, 2017; Jablansky et al., 2016). Antithetical reasoning is a form of relational reasoning, that is, the ability to discern relationships between objects, concepts and ideas. Research carried out by Alexander (2012) indicated that at least four forms of relational reasoning deserve consideration: analogy, anomaly, antinomy and antithesis. The search for qualitative methods to identify these relationships and ascertain how pervasive they are and the extent to which they are fundamental to human thought is considered to be an integral phase in any line of investigation on the subject, particularly with reference to the more neglected forms of relational reasoning, that is, antinomy and antithesis (Dumas et al., 2013).

In the following two sections we describe the Test that was used as the "starting point" for our study, and then explain the elements of novelty in our approach. In brief, our study aimed to delve further into the cognitive constraints of antithesis from a new perspective which implies a shift in focus (from an expert to a *naïve* concept of "opposite processes"), a shift in task (from a recognition task to a production task), and by designing two experimental conditions that rely on a verbally based elaboration (which is supposedly more analytical and conscious) and an iconic based elaboration (which is supposedly more automatic and holistic) of the target process to be transformed into its opposite.

(A) Antithesis according to the Test of Relational Reasoning (TORR)

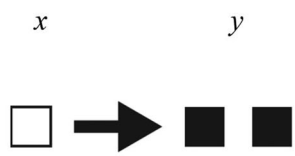
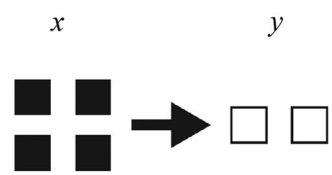
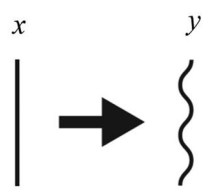
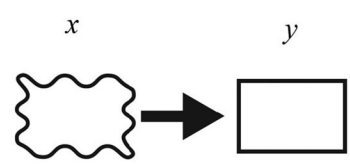
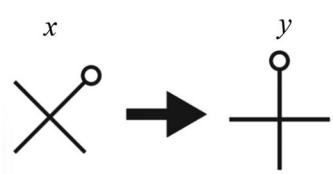
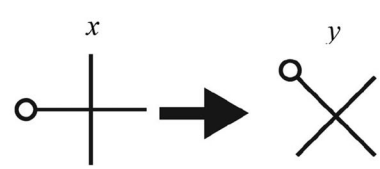
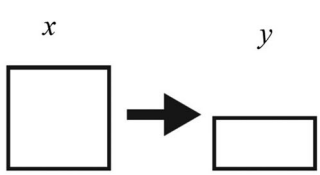
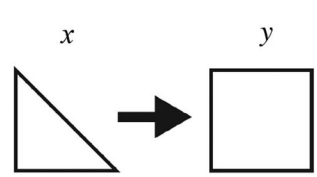
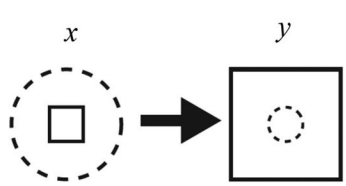
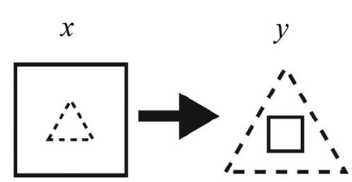
Relational reasoning generally concerns "higher-order relations", or relations between relations, since these depend on lower-order relations within and between sets of elements (Dumas et al., 2013). Recently, Alexander (2016) proposed a conceptual distinction between relational *reasoning* in the strict sense and relational *thinking*. This distinction is also useful in that it helps us to clarify the point of view described in the present study. Relational thinking implies a level of reasoning processes which is more spontaneous, automatic and unaware than other processes relating to the recognition and establishment of relations which are, conversely, more intentional and effort demanding. The latter is referred to by Alexander (2016) as relational reasoning in the strict sense.

An operationalisation of antithesis in terms of relational *reasoning*—and a measurement of the ability to identify this relation—can be found in one section of the Test of Relational Reasoning (TORR) developed by Alexander (2012) (see Alexander et al., 2015). The TORR is used to measure the aforementioned four forms of relational *reasoning* (i.e. analogy, anomaly, antinomy and antithesis) in relation to visual stimuli. A parallel test (v-TORR) was developed by the same research group to measure people's ability to deal with antithetical reasoning when verbal sentences, rather than visual stimuli, are involved.

The visual stimuli used in the antithesis section of the test consist of static representations of transformation processes leading from an initial stage (*x*) to a final stage (*y*) (see Table 1). For each of the eight items in the section of the TORR test devoted to antithesis, the participant is asked to choose which of four alternative drawings represent the opposite of the process shown in the target stimulus. Two examples are given in order to familiarise the participant with the task. Feedback on which of the four is the correct answer allows him/her to understand the reasoning process they are being asked to use. As shown in the second column of Table 1, the correct answer always implies an inversion of the target transformation. For instance, if the target shows the number of squares doubled with a change in colour from white to black (i.e. the first item in Table 1, which corresponds to one of the two example items used in the TORR), the opposite process is assumed to be that which shows the number of the squares halved and a change in colour from black to white.

The correct answer in the TORR was designed to be one example of the oppositional process that participants had been asked to conceptualise and was not meant to be a single univocal opposite of the given diagram. Furthermore, the participants had been asked to conceptualise the opposite of the process and not the opposite of the specific shapes involved, henceforth they were first supposed to identify the abstract process relating to the figure, then conceptualise the opposite of that process, and finally select an example of that oppositional process. The task used in our study was intentionally a kind of "in-between" with reference to the requirements of abstraction presupposed by

Table 1. Five of the target stimuli used in the antithesis section of the Test of Relational Reasoning (TORR). The instructions to participants in the TORR were to choose which of four alternative drawings show the "opposite process" (the correct answer is shown in column II). The five target processes shown in column I are also used in our study.

Target stimuli (target process)	Opposite process according to the TORR (correct answer)
	
	
	
	
	

the TORR and a typical perceptual task—as we will see in the next section where we present the shift in perspective underlying our research questions.

The items used in the TORR are simple geometric diagrams which aspire to be an adequate measure of the ability to identify the relationships of analogy, anomaly, antinomy and antithesis, according to the precise theoretical and/or operational definitions which are present in the literature. These items aspire to be culture and semantics free since one of the main goals of the authors was to measure relational reasoning also whilst controlling for potentially confounding factors (such as prior knowledge or language). With the aim of focusing directly on *fluid* rather than *crystallised* cognitive abilities, the authors of the TORR constructed a test which was entirely composed of figural sets, in which all the information needed to solve the problem (i.e. identifying which of the alternatives best fit the definition of the relationships being

studied) was contained within the problem itself (Alexander et al., 2015). As the authors point out in the aforementioned paper (Alexander et al., 2015), this method has been used in cognitive assessment tools for three-quarters of a century (from Cattell, 1940 and Raven, 1941, onwards), and is generally accepted today as a valid method for limiting the influence of prior knowledge and culturally relevant experiences (Krigbaum et al., 2012). The items of the TORR were created by means of a brainstorming process involving a small sample of qualified scholars (two advanced graduate students of science education, two of mathematics education and a professor of human development). In-depth interviews in pilot studies were used to check whether each section of the test was understood as assessing the same relationship and whether the four relationships that the four sections of the TORR focus on were recognised by the participants as corresponding to analogy, anomaly, antinomy and antithesis (Alexander et al., 2015).

(B) The present study: A shift in perspective

In the previous paragraph we briefly touched upon the distinction between relational thinking and relational reasoning and the existence of a test (TORR) which assesses the ability to recognise "the opposite" of visual stimuli representing a process of transformation from *x* to *y* in terms of relational reasoning. In particular, we concentrated on the methodological aspects underlying the creation of the stimuli and the possible answers in the TORR since this helped us to understand the differences in procedure and goals with regard to the present study.

The perspective taken in this paper represents an innovation in that it aims to further expand on the idea of an "antithetical relation" between two processes. This was done by means of exploring the idea of an "opposite process" (according to an adult) based on an *intuitive understanding* of the concept. This is the reason why two choices relating to the experimental design and the task were made.

Firstly, we did not provide the participants in the experiment with example items from which they might "learn" the features we wanted them to work on. Providing examples is perfectly meaningful in the case of the TORR since it aims to assess people's ability to recognise a specific type of relationship which they are able to identify by studying the example items. Conversely, since the goal of our study was to understand how adults would *spontaneously* understand the expression "an opposite process", it was crucial that no suggestions should be given. We based our investigation on the results of a *production type task*, that is, the participants were asked to imagine and then draw the opposite of the simple diagrams presented which represented "*x* to *y*" processes. We did not offer them alternative responses from which to choose. They were requested to draw (rather than verbally describe) the opposite transformation process (a) since there is evidence that graphic and verbal processing does not follow the same path in insight problem solving (Ball et al., 2015; Schooler et al., 1993: Schooler & Melcher, 1995) (b) so that it would be possible to compare our results with the TORR graphical answer choices more precisely.

Moreover, the participants were not explicitly invited to activate an abstract conceptualisation of the transformation, thus encouraging them to rely more on the visual features of the diagrams. It is also to be noted that they were not requested to draw the opposite *of the figures they were shown*, but the opposite of the *transformation process* represented. The present task was intentionally of an "in-between" type with respect to the TORR approach (which assumes an abstract conceptualisation of the transformations underlying the stimuli) and to previous studies on the perception of opposites with static figures in which the participants were asked to draw (or simply identify) the opposite figure (e.g. Bianchi & Savardi, 2006, 2008).

Our interest in exploring the oppositional structure of *visual stimuli* represents a facet of the general interests of our research group with regard to searching for the *perceptual* constraints embedded in the naïve idea of opposites. From previous studies (e.g. Bianchi & Savardi, 2008; Bianchi et al., 2017a, 2017b), opposition emerges as a phenomenally evident, self-organised perceptual structurewhich is central to spatial perception. This emerged from the results of various studies that widely explored human spatial perception in relation to ecological scenes and objects (e.g. Bianchi et al., 2011, 2013, 2011, 2011; Bianchi et al., 2017b; Burro et al., 2018a, 2018b), simple two-dimensional figures (see Bianchi & Savardi, 2006, 2008; Bianchi, et al., 2017a), acoustic stimuli (see Bianchi, Burro, et al., 2017) and simple motor gestures (see Bianchi et al., 2014; Bianchi & Savardi, 2008). The findings from these studies were consistent and appear to substantiate the conclusion that opposition is already defined on a perceptual level in cases where there is

a maximal difference (concerning one or a few aspects) within a condition of global invariance. This characterises two configurations that are perceived as opposite to each other. What is interesting in Savardi & Bianchi's experimental studies on opposites (2001–2019) is the phenomenological approach: the focus is on what naïve subjects consider to be the "opposite" of a figure or an object or a gesture and the "definition" of the requisites described thus far are identified "a-posteriori" (i.e. experimentally) and not "a-priori" or theoretically. To date, none of these studies has focused on what naïve subjects consider to be the opposite of transformation processes displayed in visual diagrams.

At this point, it becomes clear why we thus based our investigation of the naïve idea of an "opposite process" on the visual target stimuli of the antithesis section of the TORR rather than using a new, independent set of items. We wished to make a direct comparison between the naïve idea of an "opposite process" which emerged from this experimental task and that presupposed by the correct answers to the TORR (where a process of abstraction is involved as well as an "expert" idea of antithesis). The expectation was that this would reveal something interesting about the characteristics of the naïve versus expert (i.e. TORR) patterns of response and the main differences between them.

A third innovation with respect to the TORR concerns testing the impact of the participants giving an *initial verbal description* of the target stimuli (probably involving a more conscious, analytical process) on the number and type of drawings then produced by the participants. This is discussed in detail in the presentation of the study (see next Section, point 3).

The study

In the present study, we presented the participants with simple black and white diagrams representing a process, with *x* and *y* being, respectively, the initial and final phases of a process. A horizontal arrow between *x* and *y* represented the direction of the transformation (see the stimuli items shown in Table 1, col. I). There were two specific experimental conditions and the main task required the participants to draw what they considered to be "the opposite process" with respect to the process depicted in the stimulus item. They were allowed make up to three different drawings.

There were three main aspects which were the focus of this investigation.

(1) Patterns of response. Our main goal was to explore whether invariant patterns emerged from an analysis of the participants' responses indicating cognitive constraints relating to the definition of "an opposite process". This was with reference to the spontaneous understanding of naïve people and not based on a-priori, theoretically modelled definitions, as discussed in the introduction. One basic aspect we were interested in investigating concerned whether people would tend to "reverse" the process starting from the original stimulus (i.e. they would start with the *y* of the original stimulus and "go backwards" towards *x*) or would use the same starting point, that is *x*, and invent a process that would lead to an opposite outcome, that is the opposite of *y*.

In more general terms, we might question whether the opposite of a visual process displaying "organizing elements which are placed in an initial disordered state to form a simple ordered configuration" is a disarrangement of the final, simple and ordered, configuration, so that it goes back to the original disordered state; or whether it is rather a process starting from the same disordered state and leading for example, to a complex as opposed to a simple configuration, or to a rounded as opposed to a pointed configuration.

(2) Univocality. We wished to assess the extent to which the concept of an "opposite process" is univocal. In other words, the question is whether people have in mind only one idea of what the opposite of a process might be or they are able to come up with various alternative versions. In this sense**,** the concept of univocality can be linked to evidence coming from literature in the field of linguistics on the subject of antonyms with regard to canonicity. The term canonicity refers to the extent to which antonyms are both semantically related and conventionalised in memory, text and discourse (Murphy, 2003, p. 31). Antonyms can be distinguished in terms of whether they are canonical or non-canonical, for instance, by observing the number of different alternatives people think of when requested to find the opposite of a word (Paradis et al., 2009). The term univocality also arose in connection with the results which emerged from the perceptual studies mentioned in the introduction. It refers to what the naïve

subjects who took part in the studies considered to be the opposites of, for example, shapes and figures, body positions and acoustic patterns such as a simple sequence of musical notes. In all of these studies, the participants were remarkably consistent in their responses, as if the intuitive concept of "opposite", even when applied to a perceptual pattern, was univocal. In the present study, we addressed the issue of univocality by counting the number and frequency of different solutions that each individual provided in response to the instruction to "draw the opposite". It was made clear to them that they were allowed to imagine more than one potential response.

(3) The influence of the task. We decided to add a condition in which the participants were asked to give a preliminary written verbal description of the image used as a stimulus before starting to work on their own drawings. The aim was to ascertain whether this would affect their responses, both in terms of the number of drawings and the response pattern. This was called the Verbal-Iconic condition. In the other condition, the Iconic-Verbal condition, the participants were asked to give a written verbal description of the image in the stimulus only after they had done their own drawing(s). In both conditions, the participants were also requested to give a written description of their own drawing(s) in addition to their description of the stimulus.

Our two experimental conditions were designed in order to test whether they resulted in two different types of cognitive relational processes. The first (i.e. Verbal-Iconic) is more conscious and probably less automatic and is thus more similar to what Alexander (2016) called relational *reasoning* in the proper sense. The second (Iconic-Verbal) is, in contrast, more immediate and more probably perceptually guided and thus more similar to what Alexander (2016) called relational *thinking*. In writing their verbal descriptions, the participants necessarily focused on the various different visual properties that they noticed in the image. For example they could describe stimulus 1 (see Table 1) as "A single small white square, lying on one of its sides, which turns into two small black squares which are the same size as the initial square, but are positioned horizontally, one next to the other, at a distance which is less than the length of the side, and aligned with the initial white square on the same horizontal plane". The hypothesis was that if a more conscious investigation was carried out at the very beginning of the task, that is before doing their own drawing (s), it would potentially alter the way in which the participants then analysed the target stimulus, both in terms of whether they anchored on the x or y stages and in terms of the number of transformations they noticed. This, in turn, might stimulate them to focus on more than one of the properties characterising the stimulus and thus come up with solutions involving transformations of many of the original properties, either all together in one drawing or separately in different drawings (thus leading to a greater number of drawings). For example, one drawing might focus on the colour (i.e. white versus black) and invert the colours of the squares, while a second might focus on the fact that the squares were the same size and make them different sizes. Another drawing might focus on the number of squares and bisect the area of the original square rather than doubling it, or focus on the reciprocal position of the squares, placing the final squares vertically rather than horizontally. Conversely, in the Iconic-Verbal experimental condition, responses were based only on a visual exploration of the stimulus. In this case, a more global coding process was likely to be activated. According to what we know from previous studies on the production of opposites (see introduction), this should mean that responses will be based on the extreme transformation of one or two characteristics of the initial stimulus and not on solutions involving the simultaneous transformation of many features. It is, however, clear that the stimuli which were used in the present study are very different from those used in the literature cited (i.e. simple bidimensional figures, human postures, visual and acoustic patterns).

Method

Participants: 40 Italian undergraduate students (30 females, 10 males; $M_{age} = 23.075$, $SD = 3.394$) took part in the study. They were recruited at the beginning of a Psychology course unrelated to the subject at the University of Verona (Italy). They all gave their informed consent prior to the beginning of the experiment. The study conforms to the ethical principles of the declaration of Helsinki (World Medical Association, 2013) and was approved by the

ethical committees of the University Departments of the researchers involved in the study.

Procedure: The participants took part in the study in a university room. They were randomly assigned to one of the two experimental conditions (i.e. Iconic-Verbal or Verbal-Iconic) and were presented with the booklet relative to the corresponding condition. They were invited to follow the instructions printed in the booklet and were allowed to ask questions if something was not clear. No time limits were set in order to allow the participants to do as many drawings as they wished. The task needed no more than 20 min to be completed.

The two experimental conditions differed in that one (the Verbal–Iconic condition) had an additional requisite—the participants were explicitly asked to give a verbal description of the visual stimulus *before* drawing the opposite process. In the Iconic-Verbal condition, the participants gave their iconic response (i.e. their own drawing) immediately after observing the stimulus and only *after* that did they write a description of the initial stimulus.

Materials: Two booklets were prepared for the study (a paper and pencil task), one for each experimental condition. Each booklet consisted of seven A4 sheets.

The first page was for the participants' individual details (e.g. age and sex). It also presented an initial set of instructions. In both conditions, they were informed that they would see five simple diagrams, each representing something (x) that turned into something different (y), and that the black arrow between x and y represented the idea of a transformation process linking x and y. The specific instructions for each experimental condition were, in the Iconic-Verbal condition, to "look at each image, one by one, and draw what you consider to be the opposite process"; in the Verbal-Iconic condition the instructions were to "write a detailed verbal description of the process of transformation represented in each image and then draw what you consider to be the opposite process".

The next five pages were identical for the two experimental conditions. They presented the five diagrams used in the study (see column I in Table 1), one on each page. The order of the stimuli was randomised between participants. The size of the stimulus images ranged from 4.67–8.30 cm in width and from 2.77–4.55 cm in height. They were printed in black and white at the top of each page, in the centre, with some space left around each diagram for the written description. The remaining part of each page was divided into three horizontal sections (numbered from 1 to 3). In both conditions, the instructions indicated that the participants should do their drawings in these sections, starting with section number one and using the other sections if necessary. Each section provided enough space also for the relative written description of the response (see below). These descriptions helped the experimenters interpreting the transformations involved in the responses provided.

The last page of the booklet presented the final set of instructions. In the Iconic-Verbal condition, they consisted of asking the participants to go back to the original stimuli and write a detailed description of all them, starting with the first. They were also requested to do the same for their own drawing(s). In the Verbal-Iconic condition, in this page of the booklet the instructions were to write a description of the response drawings, starting with those corresponding to the first stimulus.

Classification of the responses: To start with, 16 logical possible response patterns were identified. These corresponded to the various ways in which the $x \rightarrow y$ process could be modified in order to transform it. The aim was to investigate two aspects which we were particularly interested in (i.e. without reference to the specific characteristics of the original stimuli which had been modified, e.g. the colour, the size, the orientation, etc.).

(a) We wished to understand whether the participants had taken x or y in the original stimulus as their starting point. This is manifested in the formula used to describe each pattern (see Table 2): those in the form "$x \rightarrow \ldots$." indicate that the original x is taken as the starting point in the "opposite process" imagined by the participant; the patterns in the form "$y \rightarrow \ldots$" indicate that y, the end point of the stimulus image, is taken as the starting point in the "opposite process".
(b) We also wanted to determine whether the x or y in the original stimulus were replicated as such or were somehow modified. This is reflected in the formulas used to describe each pattern by a simple reference to x and/or y or by the use of xm (which means modified x) or ym (which means modified y).

In order to test Univocality, we analysed the frequency with which the participants did, respectively, one, two or three different drawings for each stimulus. One single drawing meant that they thought of

only one possible opposite process (i.e. a unique opposite) and two or three drawings meant that they had come up with more than one potentially opposite process (i.e. multiple opposites).

The coding of all of the responses was done by two independent judges who were among the authors of the present paper (Cohen's K = 0.9; controversial cases were discussed until a consensus was reached).

Data Analysis: Generalised Mixed Effect Models (GLMM) were used to analyse the data. For the purposes of the hypotheses and experimental design of the study, both the variability related to the Participants and to the Items were considered random effects in all of the analyses; they are simply exemplars of a general category (Barr et al., 2013; Borenstein et al., 2009). Response Patterns, Number, Response Ranking, and the two Experimental conditions were, in turn, the fixed effects studied.

All analyses were carried out using the "lme4" (Bates et al., 2015), "car" (Fox & Weisberg, 2019), "emmeans" (Length, 2019), and "effects" (Fox & Weisberg, 2018) packages of the statistical software program R 3.6.1. We performed Analysis of Deviance Table (Halekoh & Höjsgaard, 2014). Bonferroni corrections were applied to the post-hoc comparisons.

Results

(1) Patterns of response: the most frequent patterns

A Generalised Linear Mixed Effect Model (GLMM) was conducted on the frequency of the various patterns. The main factors were Pattern (16 levels), Experimental Condition (Iconic-Verbal; Verbal-Iconic) and response Ranking (i.e. whether it was first, second or third drawing).

A significant main effect emerged for Pattern ($\chi 2_{(12,\ N=269)} = 725.783$, $p < .001$). Post hoc tests revealed that *y→x* was the most frequent Pattern, followed by *ym→xm* (*y→x* vs *ym→xm*: contrast estimate = 1.8917, SE = 0.189, df = 295, t-ratio = 9.988, $p < .0001$) and *xm→ym* (*y→x* vs *xm→ym*: contrast estimate = −2.3917, SE = 0.189, df = 295, t-ratio = −12.628, $p < .0001$), and then by all the other patterns. The differences between the first three and these last patterns were significant by at least $p < .001$.

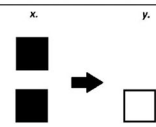
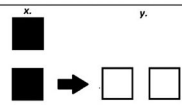
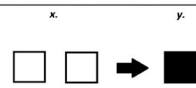
Significant interactions, however, also emerged (see Table 3 for the post hoc tests discussed here below). The interaction between Pattern and Experimental condition ($\chi 2_{(12,\ N=269)} = 47.188$, $p < .001$; see Figure 1) indicates that visual access only to the initial stimulus (Iconic-Verbal condition) or visual access plus a written description (Verbal-Iconic condition) modulated the participants' responses. A comparison between the patterns relating to the Iconic-Verbal condition revealed that two patterns were significantly more frequent than all of the other patterns (by at least $p < .001$), that is, *y→x* and *ym→xm*, with no significant difference between the two. As the formula indicates, these are both patterns which are anchored to the outcome of the process in the original stimulus (i.e. *y*) and oriented in the reverse direction (i.e. towards *x*). They only differ in that the former is a pure reversal since the order of *x* and *y* in the stimulus is simply reversed, whereas the latter includes modifications of the original *x* and *y*. These modifications generally referred to features relating to orientation and position, for example concerning dimensions such as upwards versus downwards. No other differences emerged between the other, less frequently used patterns, except that *xm→ym* was more frequent than the least used pattern (*xm→x*).

A comparison of the frequency of the 16 patterns relating to the Verbal-Iconic condition revealed that *y→x* (i.e. a pure reversal) was significantly more frequent than all of the other patterns, including *ym→xm*, which was used with the same frequency as the other less frequently used patterns. Conversely, *xm→ym* was used more frequently in this condition than the other patterns (*x→x*, *xm→xm*, *y→ym*, *ym→ym*, *xm→y*, *y→xm*); *xm→ym* is a pattern which is anchored to the starting element of the original stimulus (*x*) rather than the final element (*y*).

Further comparisons *between* the Iconic-Verbal and Verbal-Iconic conditions did not reveal any significant differences concerning either the frequency of the *y→x* pattern or the *xm→ym* pattern except for the fact that *ym→xm* was, in effect, significantly more frequent in the Iconic-Verbal than in the Verbal-Iconic condition.

The significant interactions between Pattern and response Ranking ($\chi^2_{(24,\ N=269)} = 790.895$, $p < .001$) and between Pattern, response Ranking and Experimental condition ($\chi^2_{(24,\ N=269)} = 62.180$, $p < .001$) indicate that the frequency with which these various Patterns were used, depended also on whether the first, second or third drawing done by the participants was taken into consideration. The latter interaction is shown in Figure 2, which clearly shows that the difference only concerns the first drawing.

Table 2. The 16 patterns indicating the possible response types (a drawing which exemplifies the pattern is shown on the right of each formula).

Target stimulus n. 1					
Response Pattern formula		Example	**Response Pattern formula**		Example
1	*x→x*		9	*x→y* (coinciding with the given stimulus)	
2	*xm→x*		10	*xm→y*	
3	*x→xm*		11	*x→ym*	
4	*xm→xm*		12	*xm→ym*	
5	*y→y*		13	*y→x*	
6	*ym→y*		14	*ym→x*	
7	*y→ym*		15	*y→xm*	
8	*ym→ym*		16	*ym→xm*	

In the Verbal-Iconic condition, *y→x* is significatively more frequent than all of the other patterns (by at least $p < .001$), including the two patterns that follow in terms of frequency, that is, *xm→ym* and *ym→xm* (with no significant differences between the two). This reflects the general result shown in Figure 1. Conversely, in the Iconic-Verbal condition, *y→x* is more frequent than all of the other patterns (by at least $p = .001$), including *ym→xm* ($EST = 2.60$, $SE = 0.455$, $df = 295$, t-ratio = 5.720, $p = .001$), whereas the main effect (Figure 1) showed no differences between these two patterns. (i.e. *y→x* and *ym→xm*). No significant difference between the patterns emerged when the second or third drawings done by the participants were considered. Therefore, in both conditions there is a clear preference for reversal (i.e. *y→x*) as a first choice.

(2) Univocality: the average number of potential "opposite processes" drawn by the participants

A Generalised Linear Mixed Effect Model (GLMM) was conducted on the number of times the

participants did one drawing, two drawings or three drawings, respectively for each stimulus. The Number of drawings and the Experimental Condition (Iconic-Verbal; Verbal-Iconic) were the two main factors in the model, Item and Participants were the random factors. A significant main effect emerged for Number ($\chi^2_{(2,\ N=269)} = 271.787$, $p < .001$), without any interactions with Experimental Condition ($\chi^2_{(2,\ N=269)} = 0.491$, $p = .782$). As shown in Figure 3 and confirmed by Bonferroni post-hoc tests (Table 4), one drawing only was the most frequent response. In cases where the participants did more than one drawing, instances with two drawings were significantly more frequently than three. Expressed in percentages, 72.5% of the participants drew only one potential opposite process, 20.5% drew two and 7% drew three (Figure 3).

A further analysis was conducted on the subset of the data relating to multiple responses (i.e. two or three drawings for the same stimulus). We recoded all of the responses as single or multiple (independently of whether participants did two or three drawings) in order to ascertain the frequency with which the multiple responses were all anchored onto the same stage (either *x* or *y*), and how frequently they were anchored onto different stages (i.e. sometimes *x*, other times y). For the purposes of this analysis, we were no longer interested in which pattern was followed but rather only whether the patterns went from *x* to *y* ($x^* \rightarrow \ldots$) or vice versa ($y^* \rightarrow \ldots$). The idea was that if the participants anchored multiple responses onto the same stage (either *x* or *y*), this would indicate that they were fixed on the notion that an opposite process is based on the end of the target process (i.e. *y*) or on its beginning (i.e. *x*). If they anchored their multiple responses on different stages, this would indicate that their idea of an opposite process included both the idea of reversing the original process ($y^* \rightarrow \ldots$) and starting from the initial stage while modifying the outcome of the process ($x^* \rightarrow \ldots$).

A GLMM (binomial, logit link function) was conducted on the Type of multiple response (i.e. Same, Different anchor) in the two experimental conditions (i.e. Iconic-Verbal, Verbal-Iconic), with Participants and Items as random factors. The interaction between Type of multiple response and Condition turned out to be significant ($\chi^2_{(2,\ N=52)} = 10.290$, $p < .001$). As shown in Figure 4 in the Verbal-Iconic condition, multiple responses were more frequently anchored to different stages of the target process (sometimes *x*, sometimes *y*) than on the same stage. This did not hold for the Iconic-Verbal condition. We will come back to this finding in the final discussion.

Final discussion

The overall picture that emerges from the results of this investigation into people's naïve idea of "an opposite process" can be summarised into three main points.

Firstly, the participants in the study interpreted the concept of the opposite of a transformation process in an almost univocal way: 93% of participants came up with *a maximum of two* alternative opposites and the majority of them (72.5%) drew only *one* opposite process as their response. This was despite the fact that the participants had been explicitly told that they could give three alternative potential solutions. Furthermore, they certainly had sufficient time since there were no time limits and the task in any case could be completed in a relatively short time (no more than 20 min). This result

Table 3. Bonferroni post-hoc tests concerning the effect of the interaction between Pattern and Condition (I-V = Iconic-Verbal; V-I = Verbal-Iconic) on the response frequency—See Figure 1).

Post-hoc tests on	*Contrast Estimate*	*Standard Error*	*df*	*t*-ratio	*p*-value
y→x (I-V) vs ym→xm (I-V)	0.8667	0.262	295	3.302	$p = .3499$
y→x (I-V) vs xm→ym (I-V)	−2.2667	0.262	295	−8.637	$p < .0001$
ym→xm (I-V) vs xm→ym (I-V)	−1.4000	−1.4000	295	−5.335	$p = .0001$
xm→ym (I-V) vs xm→x (I-V)	−1.0000	0.262	295	−3.810	$p = .0549$
y→x (V-I) vs ym→xm (V-I)	1.5333	0.268	295	5.723	$p < .0001$
ym→xm (V-I) vs x→ym (V-I)	−0.6000	0.273	295	−2.197	$p = 1.0000$
xm→ym (V-I) vs x→x (V-I)	−1.4167	0.273	295	−5.186	$p = .0001$
xm→ym (V-I) vs xm→xm (V-I)	−1.4167	0.273	295	−5.186	$p = .0001$
xm→ym (V-I) vs y→ym (V-I)	−1.2833	0.273	295	−4.698	$p = .0013$
xm→ym (V-I) vs ym→ym (V-I)	−1.2833	0.273	295	−4.698	$p = .0013$
xm→ym (V-I) vs xm→y (V-I)	−0.6000	0.273	295	−2.197	$p = 1.0000$
y→x (I-V) vs y→x(V-I)	−0.6667	0.268	295	−2.488	$p = 1.0000$
ym→xm (I-V) vs ym→xm (V-I)	1.3833	0.268	295	5.163	$p < .001$
xm→ym (I-V) vs xm→ym (V-I)	−0.4167	0.268	295	−1.555	$p = 1.000$

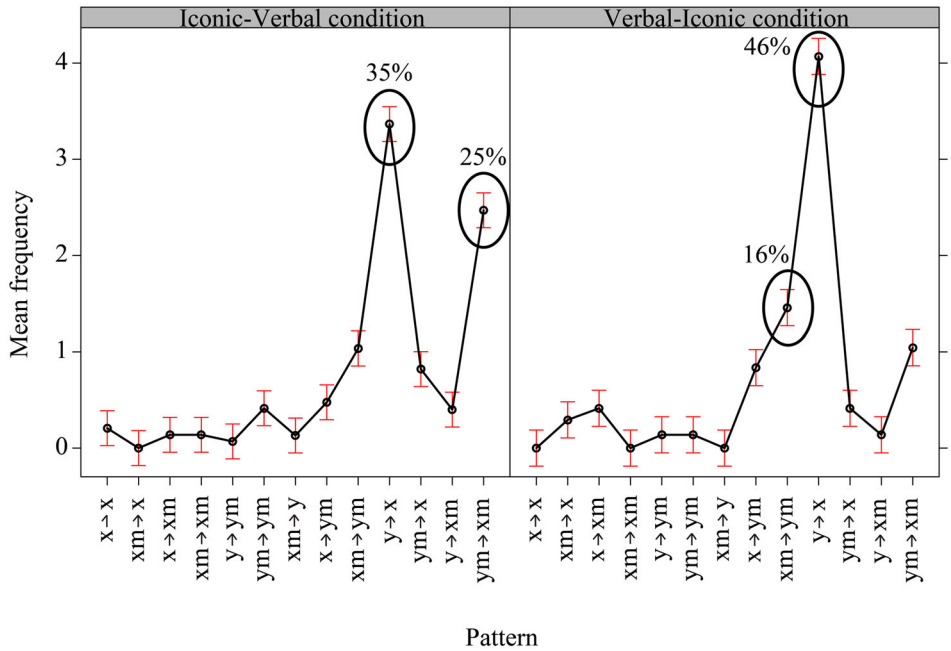


Figure 1. Effect plot of the interaction between Pattern and Condition in terms of the frequency of use of the various patterns (on a Logarithmic scale). The bars represent the 95% confidence interval. In the graph, the frequency of the first two patterns is also reported as a percentage (of the total number of responses).

tells us that when a naive participant imagines the opposite of a transformation process, he/she tends to recognise *only one* process and *not several* processes as being opposite. This appears to be in line with the findings from previous studies on the perception of opposites (see the introduction) which indicated that naïve observers tend to both produce and perceptually recognise only one good opposite of a graphic, motor or acoustic configuration. This might suggest that the principle of the *perceptual univocality of opposition* also extends to both cases in which imagining transformation processes is more automatic and cases in which it is more conscious.

Secondly, the *first response* that participants gave (which was arguably the most obvious or the most convincing to them) consisted of simply reversing the initial and final stages, that is going from *x*→*y* (the target stimulus) to *y*→*x*, without modifying the characteristics of *x* or *y* in any respect. This held in both the Iconic-Verbal and the Verbal-Iconic conditions according to the results of an analysis of the Patterns in relation to the Ranking of responses. Our stimuli were graphical structures which were *spatially oriented* from the first stage (*x*) to the final stage (*y*) and the *first response* that participants gave in both experimental conditions consisted of *simply reversing the direction of the transformation* by inverting the initial order of the stages, that is, they did not modify any of the original characteristics. This finding extends what we know from previous studies on the perception of opposition in relation to two simple bidimensional spatial oriented figures (see the introduction), that is, that in order to be perceived as opposite, the new figure must maintain most of the original features while direction is inverted (e.g. from upwards to downwards).

Thirdly, a preliminary task involving writing a description of the target stimulus had no effect in terms of modifying the participants most frequent first response (in fact, as mentioned earlier, *y*→*x* was the most frequent first response in both conditions) which suggests it is a solid pattern. It did not generically increase the number of responses produced either (this might simply mean that the participants were more engaged due to the extra initial task). This prior task did, however, result in a difference regarding the other *pattern* of response which came up frequently. In the Iconic-Verbal condition, the two most frequently used patterns were *y*→*x* and *ym*→*xm*, which are both anchored to y, with further modifications (*ym*→*xm*) or without further modifications (*y*→*x*). Conversely, in the Verbal-Iconic condition, the most popular alternative response to the most obvious *y*→*x,* involved a

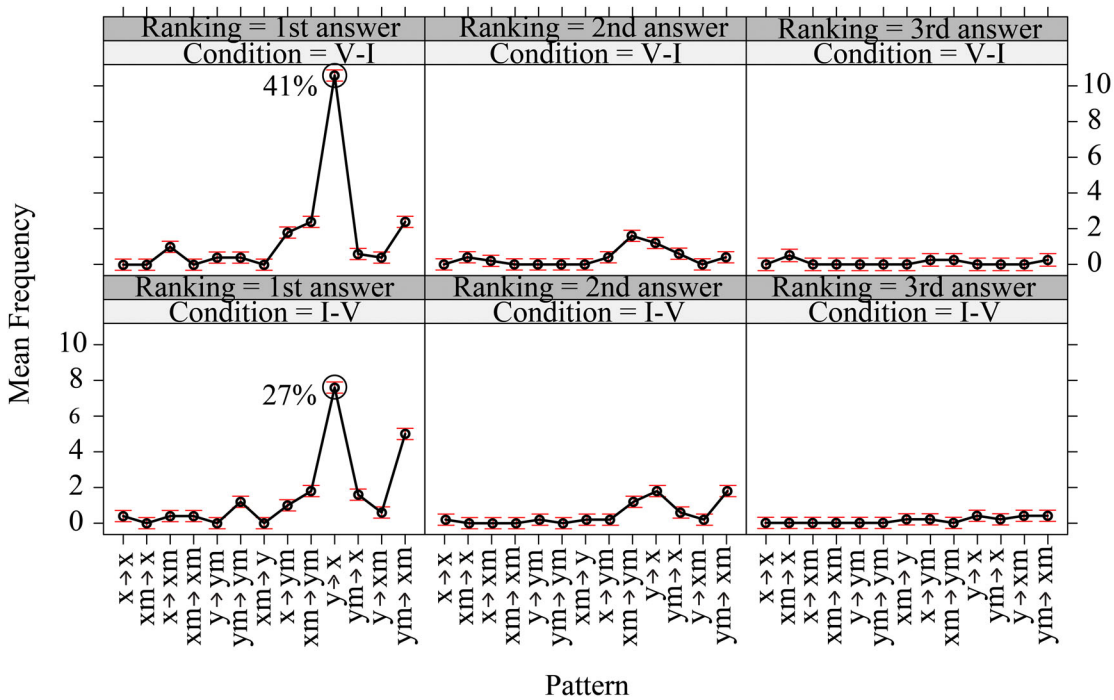


Figure 2. Effect plot of the interaction between Pattern, Condition and response Ranking (i.e. first, second or third drawing) in terms of the frequency of use of the various patterns (on a Logarithmic scale). The bars represent the 95% confidence interval. In the graph, the frequency of the first pattern is also reported as a percentage (of the total number of responses).

process that started with a modification of the initial stage (*x*) and led to a modification of the end stage (*y*), that is, *xm*→*ym*. There was not a reversal of the two stages. This means that in the Verbal-Iconic condition, the second most frequent response involved a transformation from *x* to *y*. The finding that both of the most frequent patterns which emerged in the Iconic-Verbal condition (i.e. those which are associated with less conscious, more automatic responses) are anchored to an inversion of the x and y stages appears to support the hypothesis that in this condition (as compared to the Verbal-Iconic condition which is associated to more conscious, less automatic responses), the participant was to some extent more conditioned by the perceptual requirements of opposition. The direction of the transformation (i.e. *y*→*x*) confirms the relevance of orientation in the perception of opposition relating to visual patterns, as previous studies have demonstrated (see Bianchi & Savardi, 2008).

In order to illustrate more effectively the differences between the three most frequent response patterns found in the present study and at the same time expand their application to a more ecological context, we would like to provide an example. Let's imagine a process whereby a pile of bricks (stage x) is transformed into a skyscraper (stage y), so a pile of bricks → skyscraper. In both

Table 4. Bonferroni post-hoc tests on the main effect of Number of responses (1, 2 or 3 alternative "opposite processes" drawn by the participants).

Post-hoc tests on	*Contrast Estimate*	*Standard Error*	*df*	t-ratio	*p*-value
1 vs 2	1.108	0.089	295	12.426	< .001
1 vs 3	1.142	0.092	299	15.397	< .001
2 vs 3	0.313	0.092	299	3.396	= .002

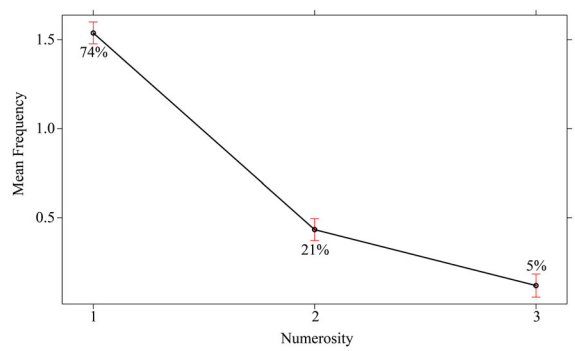


Figure 3. Effect plot of the Main effect of Number of responses (on a Logarithmic scale). Error bars represent the 95% confidence interval. The data are also reported as a percentage of the total number of responses.

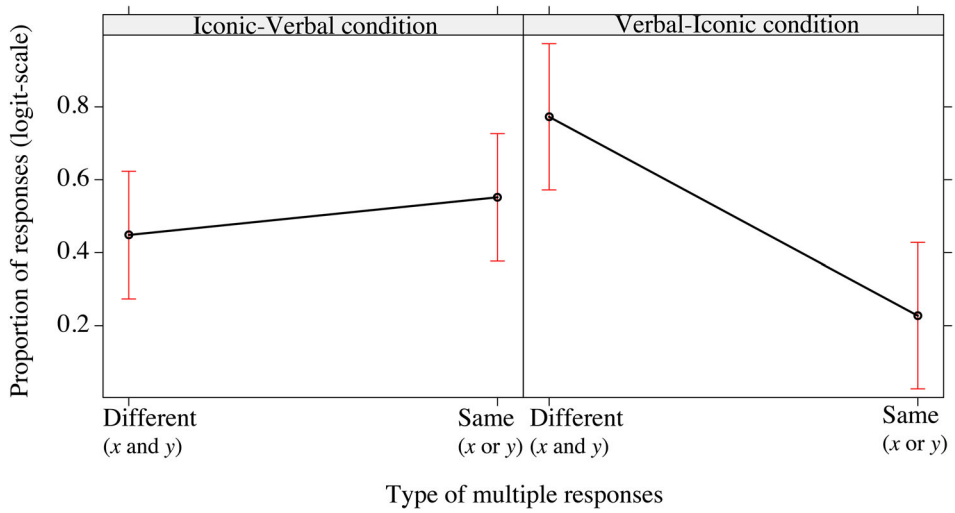


Figure 4. Effect plot of the interaction between Condition (Iconic-Verbal; Verbal-Iconic) and Type of multiple response (Same anchor—i.e. on either *x* or *y*; Different anchor—i.e. once on *x* and another on *y*) on the proportion of responses. Error bars represent the 95% confidence interval.

of the experimental conditions addressed in our study (i.e. Iconic-Verbal and Verbal-Iconic), the process epitomising the idea of opposition would be to transform the skyscraper into a pile of bricks (skyscraper →a pile of bricks). In the Iconic-Verbal condition, the second most frequent response would be, for example, an underground parking lot (vs. a skyscraper) that is transformed into a pit full of bricks (vs. a pile of bricks). Here, both the order of the two stages of the reference process and the upward-downward spatial characteristics are changed. In the Verbal-Iconic condition, however, a second response might involve an opposite process in which, for example, a row (vs. a pile) of bricks is transformed into a hut (vs. skyscraper). Here the original order of the stages remains unchanged, but the spatial characteristics relating to "vertical development-horizontal development" would be changed.

That there was an association between the pre-task and responses based both on a reversal (*y*→*x* and a modification of the stages in the original *x*→*y* order was confirmed by an analysis of the subset of cases in which individual participants gave multiple responses to a single stimulus. Only in the Verbal-Iconic condition did multiple responses consist more frequently of drawings with varying anchor points, that is, if the opposite transformation process was anchored on *x* in one drawing, it was anchored on *y* in another.

What can we learn, in conclusion, from the results of this investigation and what are the limits?

Our findings provide further evidence to that collected in previous literature (on very different content domains and with very different experimental stimuli) supporting the hypothesis that people have an intuitive idea of opposition. This subject has been investigated with similar results in the field of language studies, where it is widely acknowledged that antonyms are primal linguistic structures common to all languages and about which people have an intuitive understanding (e.g. Fellbaum, 1998; Jones, 2007; Murphy, 2003; Paradis et al., 2009). Evidence that people have an intuitive idea of what "the opposite is" also emerged from studies concerning the Psychology of Perception which have shown that people give consistent responses when asked to identify the opposite of a visual figure (in this case, simple geometrical figures, parts of an ecological scene, or configurations involving human body postures) and of simple acoustic configurations (e.g. Bianchi et al., 2014; Bianchi & Savardi, 2008; Bianchi, Burro, et al., 2017; Bianchi, et al., 2017b). The present study contributes by providing evidence supporting the concept of an intuitive understanding of the idea of opposition with reference to simple static diagrams representing an opposite transformation process. Indeed, of the 16 theoretically possible response patterns, only three patterns were frequently used. The responses that simply reversed the two stages of the process (i.e. *y*→*x*) seemed to be the one that came closest to the naïve idea of an "opposite process" that adults have. This was

independently of whether the participants had merely observed the target stimulus or whether they had also given a written description prior to carrying out the task. However, those who did not do the preliminary task (i.e. the Iconic-Verbal condition), seemed to be in some way fixed on the idea of simply "reversing" the process and only thought of *possibly* modifying some aspects of the two stages (*ym*→*xm*). Conversely, in the Verbal-Iconic condition, the pre-task exercise appeared to stimulate the participants to also consider potential solutions in which the *x* and *y* phases were not reversed, but were modified with respect to some of their features (*xm*→*ym*).

If we look at these findings from an applicative perspective, that is, in relation to contexts where stimulating people to "think of the opposite" is desirable (see the introduction to this paper), we might conclude that the Iconic-Verbal and the Verbal-Iconic conditions are not interchangeable. When there is a need for divergent thinking and creativity, it might be worth considering both a condition where explicit verbal coding is part of the task from the very beginning, and a condition where a visual analysis of the process can develop without any explicit verbal influence.

It is also interesting to go back to the distinction between relational thinking and reasoning (Alexander, 2016) mentioned in the introduction to this paper and then match the "naïve" idea of opposite processes which emerged from our study to the "expert" idea of opposites which underlies the correct answers in the TORR. A study of the differences between an adult's naïve, intuitive definition of an opposite process and other plausible definitions based on specific expertise in a subject (see the correct answer choice in the TORR) would possibly further help in terms of conceptualising the complexity of the antithesis construct in relational reasoning. With regard to the 16 transformation patterns defined in this paper (see Table 2), the correct answers to the TORR (see Table 1, column II) are, in most cases, examples of the *ym*→*xm* pattern. Therefore, according to the "expert" perspective (i.e. TORR), an opposite transformation process (determined by means of a conscious, intentional, effort-demanding and abstraction-based reasoning process) would be one characterised both by an inversion of the original stages of the target process and by a recognisable modification of those stages. It is, of course, to be noted that the correct answers to the TORR were designed to be *one possible instantiation* of an *abstract oppositional process*. As the results of our study show, the characteristics of an opposite transformation process produced by a naive subject differ from this definition in terms of pattern. In the Verbal-Iconic condition, in which the participants were asked to write a preliminary description of the visual stimulus (and thus a more conscious and less automatic graphic response was likely activated, which corresponds to those cognitive tasks which Alexander, 2016, defined as relational reasoning in the proper sense) the most frequent response was characterised *either* by the *mere inversion* of the original stages of the target process *or* by the *modification* of the characteristics of the original *x* and *y* stages *without* any inversion. On the other hand, a better correspondence was found, in terms of patterns, between the theoretical definition of an opposite process underlying the TORR and one of the two responses which was most frequently given in the Iconic-Verbal condition of our task. This condition was characterised by a more spontaneous perceptual processing of the stimulus and the resulting cognitive process is more similar to what Alexander (2016) defined as relational thinking. This might suggest further issues to be investigated.

Future studies might also investigate the preference for one of the three most frequent response patterns which emerged in the present study by means of a selection task rather than a production task. The aim would be to ascertain what naïve participants consider to be the best opposite and whether a preliminary written task had any effect on this.

In vivo studies on the role of these opposition patterns in various different human cognitive activities (such as, for example, scientific research and discovery, argumentation and persuasion, or conceptual change, etc. …) might also be an interesting research path to develop.

On the subject of any potential limitations to this study, there are three aspects that we hope might suggest further developments.

Firstly, the stimuli used in this study were static representations of processes rather than dynamic processes being observed directly. The decision to use this method was motivated by our interest in static stimuli, which are familiar in various scientific and applicative contexts and which rely on simple diagrams or depictions. The results of this study obviously cannot be generalised to other situations involving dynamic stimuli.

Secondly, there is the issue of how linguistic models consider the intuitive entrenchment of opposite word pairs to be insensitive (e.g. Gross & Miller, 1990; Sampson, 2000) or sensitive to context (e.g. Jones, 2007; Paradis et al., 2009). In terms of the present study, one might ask whether our participants' responses would have been different if the diagrams used in our task had been given a different context, for instance, if they were told that the diagrams represented a mechanical process in an engineering context, or a process regarding cell transformation in a biological context.

Finally, one might wonder whether something interesting might emerge if different population samples are considered. It would also be fruitful to compare the results of the present task to those of other tasks involving visual processing or critical reasoning. Food for thought.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Availability statement

The data that support the findings of this study are openly available in IEEE Dataport, 2020 at https://doi.org/10.21227/a8g4-9m82.

ORCID

Ivana Bianchi http://orcid.org/0000-0002-5914-6042

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