Where Word and World Meet: Intuitive Correspondence Between Visual and Linguistic Symmetry

Alon Hafri (alon@jhu.edu)
Department of Psychological & Brain Sciences and Department of Cognitive Science, Johns Hopkins University
3400 N Charles St., Baltimore, MD 21211 USA

Lila R. Gleitman (gleitman@psych.upenn.edu)
Department of Psychology, University of Pennsylvania
Stephen A Levin Building, 425 S University Ave, Philadelphia, PA 19104 USA

Barbara Landau (landau@jhu.edu)
Department of Cognitive Science, Johns Hopkins University
3400 N Charles St., Baltimore, MD 21211 USA

John C. Trueswell (trueswel@psych.upenn.edu)
Department of Psychology, University of Pennsylvania
Stephen A Levin Building, 425 S University Ave, Philadelphia, PA 19104 USA

Abstract

Symmetry is ubiquitous in nature, in logic and mathematics, and in perception, language, and thought. Although humans are exquisitely sensitive to visual symmetry (e.g., of a butterfly), linguistic symmetry goes far beyond visuospatial properties: Many words refer to abstract, logically symmetrical concepts (e.g., *equal, marry*). This raises a question: Do representations of symmetry correspond across language and vision, and if so, how? To address this question, we used a cross-modal matching paradigm. On each trial, adult participants observed a visual stimulus (either symmetrical or non-symmetrical) and had to choose between a symmetrical and non-symmetrical English predicate unrelated to the stimulus (e.g., "negotiate" vs. "propose"). In a first study with visual events (symmetrical collision or asymmetrical launch), participants reliably chose the predicate matching the event's symmetry. A second study showed that this "matching" generalized to static objects, and was weakened when the stimuli's binary-relational nature was made less apparent (i.e., one object with a symmetrical contour, rather than two symmetrically configured objects). Taken together, our findings support the existence of an abstract relational concept of symmetry which humans access via both perceptual and linguistic means. More broadly, this work sheds light on the rich, structured nature of the language-cognition interface, and points towards a possible avenue for acquisition of word-to-world mappings for the seemingly inaccessible logical symmetry of linguistic terms.

Keywords: symmetry; abstract language; visual relations; language-cognition interface; conceptual structure

Introduction

Language and thought are imbued with highly abstract logical properties, including negation (e.g., *no, not*), quantification (e.g., *some, all*), and symmetry (e.g., *similar, disagree*). Such properties and their combinatorics underlie high-level reasoning and are essential to how we construct, understand, and evaluate utterances. To what degree and how do such abstract elements correspond across different cognitive systems? In the current work, we examine the mental representation of one of these properties, symmetry, across language and vision. We focus on symmetry because — although it is an abstract property in logic — it has visuospatial reflexes that, if suitably structured, might enable cross-domain correspondence.

Symmetry is pervasive in the natural and manmade world: in biological and physical systems (as in the structure of plants, animals, or crystals), artistry (as in sculptures or paintings), and more. In general, symmetry can be characterized as invariance under transformation. In logic, symmetry is a property of binary relations that are invariant under inverse transformation: a relation R is symmetrical if and only if for all x,y: if $R(x,y)$, then $R(y,x)$ (Partee, 2008). Thus, if x equals y, then y must equal x. In geometry, symmetry is a property of figures or spatial arrays that are invariant under transformations such as rotation, reflection, or translation. For example, a butterfly's wings show reflective symmetry.

The questions we ask in our studies are the following: (1) Is the abstract logical symmetry of lexical items mentally accessible, even though it is not consistently marked morphologically (in English)? (2) Does visual processing also elicit an abstract representation of symmetry? and (3) Do representations of symmetry correspond across language and vision, and under what conditions?

A secondary motivation is that the abstract nature of symmetry presents a problem for the language learner, who must discover which words map onto such properties (Gleitman, 1990; Yuan et al., 2012). If we find a visual/linguistic correspondence for symmetry in the mind, it may shed light on the initial steps undertaken by the learner to discover which unfamiliar words map onto abstract meanings (as we outline in the General Discussion).

Symmetry in Language and in Vision

Symmetry is crucial in both logical and geometric reasoning; thus, it is not surprising that notions of symmetry appear prominently across cognitive domains. Symmetry is threaded throughout the vocabulary of natural languages, and words with symmetrical content appear in virtually every part of speech: Noun (cousin vs. father), verb (equal vs. exceed), adjective (similar vs. larger), preposition (near vs. above), and conjunction (and vs. because) (Partee, 2008; Winter, 2018). Moreover, children appear to have an adult-like understanding of such terms by four years of age (Chestnut & Markman, 2016; Miller, 1998). Logical symmetry as a property of lexical items can be appreciated by examining the examples below:

(1) The shirt and the button match.
(2) The shirt and the button match one another.
(3) The shirt matches the button.
(4) The button matches the shirt.
(5) *The shirt matches.

It can be observed that if (1) is true, it entails the reciprocal (2), as well as the sub-event in (3) and its inverse (4). Notice also that because symmetry is a property of *binary* relations, an utterance with a singular subject (5) is ill-formed (Gleitman et al., 1996).[1]

The visual system also appears to be exquisitely sensitive to symmetrical structure. *Figural symmetry* of single objects or patterns — especially reflective symmetry across the vertical (left-right) axis — is extracted rapidly and automatically, and functions as a Gestalt property of perceptual organization (for reviews, see Wagemans, 1997; Wagemans et al., 2012). It is even available to preverbal infants by 4 months of age (Bornstein & Krinsky, 1985).

Symmetry *Across* Language and Vision

Although symmetry appears in both language and vision, it is unknown whether representations of symmetry are compatible across the domains. After all, visual symmetry is traditionally considered a property of figures or patterns, while linguistic symmetry is a property of relations. For visual information to be useful for learning words with symmetrical meanings (our secondary motivation), visual stimuli must be recognized as symmetrical in a way that readily maps to the logical notion of symmetry.

One way these two notions of symmetry may be made more compatible is via binary relations, what we call "relational symmetry". Notice that we not only observe symmetry in figures or patterns (where it holds over object parts or points in space), but we also observe binary relations that are symmetrical, e.g., kisses and handshakes. Yet the extent to which we analyze such visual relations as symmetrical per se is unknown (cf. Baylis & Driver, 2001).

Nevertheless, recent work using a match-to-sample task suggests that under the right conditions, young children may process between-object symmetry as explicitly relational, rather than as a purely low-level feature (Shao & Gentner, 2019). Additionally, there is some evidence for an intuitive linguistic-visual link that operates over binary relations. Recent work has demonstrated that speakers of Nicaraguan Sign Language (NSL), an emerging language among deaf individuals, spontaneously express logically symmetrical concepts such as "high-five" iconically, using signs with mirror-reflective symmetry (Gleitman et al., 2019). Does such a linguistic-visual link also hold for non-signing observers, and what is the nature of this link?

Present Studies

Here we ask to what extent representations of symmetry correspond across these cognitive systems, and we characterize the conditions under which this correspondence is available to the mind. To do so, we utilize a cross-modal matching paradigm, which Strickland and colleagues (2015) used to reveal an intuitive bias to map linguistic telicity or "boundedness" (in English predicates) to visual boundedness (in sign language signs). We took the same approach here, using simple stimuli with geometric shapes to isolate specific aspects of visual symmetry. This paradigm bears similarities to relational match-to-sample tasks used for investigating such mappings within-domain (e.g., Hochmann et al., 2017; Shao & Gentner, 2019).

On each trial of our experiments, participants viewed a visual stimulus (symmetrical or non-symmetrical), and then had to choose between two English predicates (one symmetrical, one non-symmetrical) that best matched what they saw. Crucially, the predicates were not semantically related to the visual stimuli in any direct way, apart from the property of symmetry. We predicted that participants would prefer to associate or "match" symmetrical predicates with symmetrical visual stimuli, and non-symmetrical predicates with non-symmetrical visual stimuli.

In Experiment 1, we used dynamic visual events (symmetrical collision vs. asymmetrical launch). In Experiment 2, we collected symmetry ratings to ask whether symmetry was the best explanation for our effects. In Experiment 3, we used static objects, manipulating the number of objects (two vs. one) to change the salience of the visual symmetry's binary nature. To preview our results, we found a robust matching effect across experiments, and we determined that the binary nature of the stimulus is important to engender a robust correspondence.

Sample sizes, experimental designs, and analysis plans for Experiments 1 and 3 were pre-registered (available on our repository at the Open Science Framework [OSF]).

Experiment 1: Visual Events

Participants

60 adults (U.S. IP addresses only) were recruited from the online platform Amazon Mechanical Turk (MTurk). Participants were excluded for failure to contribute a complete dataset, reporting that they were not native English speakers, or responding with extremely fast RTs (<200ms)

[1] Although there has been controversy over whether true symmetry is psychologically real (Tversky, 1977), Gleitman and colleagues (1996) convincingly demonstrated that such items *are* logically symmetrical, with asymmetries introduced by asymmetrical (transitive) syntactic structures.

on >20% of trials. Five of these participants were excluded. Remaining fast RT trials were also excluded.

Stimuli

There were two types of stimuli: linguistic (English predicates) and visual (events between geometric shapes).

Table 1: Symmetrical (Sym) and Non-Symmetrical (Non-Sym) Predicate Pairs.

Sym	Non-Sym	Sym	Non-Sym
1. box	punch	13. interact	intervene
2. tango	lead	14. match	gauge
3. collide	hit	15. disagree	reject
4. date	befriend	16. clash	confront
5. chat	tell	17. unite	dominate
6. intersect	interfere	18. be equal	exceed
7. be identical	be inferior	19. be similar	be typical
8. combine	expand	20. agree	consent
9. separate	withdraw	21. correspond	contact
10. debate	lecture	22. negotiate	propose
11. marry	adopt	23. collaborate	contribute
12. meet	greet	24. differ	alter

English Predicates. We generated 24 pairs of predicates, each with one symmetrical and one non-symmetrical item. We selected predicates across physical, social, or mental domains. Predicates ranged from concrete to abstract.[2]

Symmetrical predicates had to meet several criteria. First, they had to exhibit *logical* symmetry: for all x,y, if *R(x,y)* then *R(y,x)*. For example, if x equals y then y equals x, but if John drowned Bill, it does not entail that Bill drowned John. Second, they had to exhibit *linguistic* symmetry: that the intransitive entails the reciprocal, as in (1) and (2) above (Gleitman et al., 1996). If x and y are equal, x and y are equal *to each other*, but the utterance *John and Bill drowned* does not entail that John and Bill drowned each other. This linguistic criterion was used to inform decisions about logical symmetry. For example, if John loves Bill, then Bill may in fact love John. But the sentence *John and Bill love* is infelicitous, and does not entail that they love each other.

To select a yoked non-symmetrical foil for each symmetrical, we found a predicate as close in meaning as we could, apart from the property of symmetry. For example, "to chat" and "to tell" are both verbs of conversing, but *chat* refers to a symmetrical relation, while *tell* does not. We also ensured that non-symmetricals failed the logical and linguistic symmetrical criteria outlined above. Predicate pairs were closely matched in length, log frequency, and concreteness (Brysbaert et al., 2014). Since in English, collectivity is sometimes marked with the prefix "co-" (e.g., *collaborate*), we also attempted to balance the prevalence of such items across the set of symmetricals and non-symmetricals. Pairs appear in Table 1.

Visual Events. In symmetrical events, two objects approached one another, made contact, and bounced away, always with equal velocity. Non-symmetrical events were Michottean causal launches: object A approached object B (static), A made contact with B, and A stopped moving as object B continued along A's same trajectory. Across trials, objects varied in color (red, green, or blue), shape (rectangle or oval), and angle of trajectory (0 to 360 degrees, 45-degree increments). Stimuli had duration 1250ms and size 640x400px. Examples are in Figure 1B; dynamic versions may be viewed on our OSF repository.

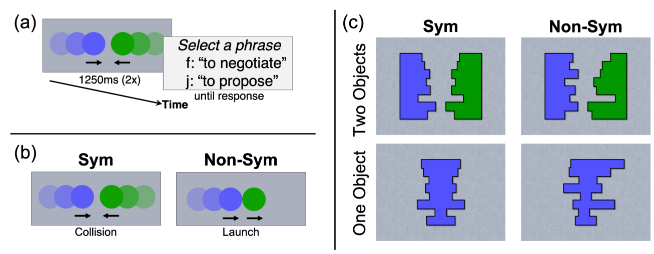

Figure 1: (a) Example trial (Exps. 1 and 3). After observing a visual stimulus, participants chose between two predicates, one symmetrical and one non-symmetrical. *(b)* Example stimuli in Experiment 1 and *(c)* Experiment 3.

Design and Procedure

The trial structure is schematized in Figure 1A. Participants were told to select the phrase that best matched the visual display. On each trial, participants viewed the same visual stimulus twice (either symmetrical or non-symmetrical), preceded by a fixation cross (350ms). The stimulus disappeared and then a predicate pair appeared below it. Each predicate was preceded by infinitival "to" (e.g., "to box" vs. "to punch"), with order of display (symmetrical or non-symmetrical first) randomized. Participants pressed the F or J key to make their choice. Note again that no predicate pair (besides the "collide"/"hit" item) was directly related semantically to the visual events. Trial order was pseudorandomized (24 trials total). Predicate pairs were randomly assigned to each stimulus.

Analysis

To test for the effect of the type of visual stimulus on predicate choice, we ran mixed effects logistic regression on trial-level data. The dependent variable was "symmetrical choice": choosing the symmetrical predicate (rather than non-symmetrical). The key independent variable was Visual Type (symmetrical vs. non-symmetrical, sum-coded). A main effect of Trial Number (centered) was included in the baseline model to account for general order effects, and its interaction with Visual Type was also tested in case the effect of interest changed over the course of the study. We tested for significance of factors in models by using

[2] We constrained our investigation to English predicates, as these have been the primary focus of previous work (e.g., Dimitriadis, 2008). However, future work may test the correspondence for other types, like kinship terms (e.g., cousin) or prepositions (e.g., near).

likelihood ratio tests on the Chi-square values from nested model comparisons with the same random effects structure.[3]

The key prediction was a significant "matching" effect: for symmetrical choices to be higher for symmetrical vs. non-symmetrical visual stimuli (which would manifest as a main effect of Visual Type).

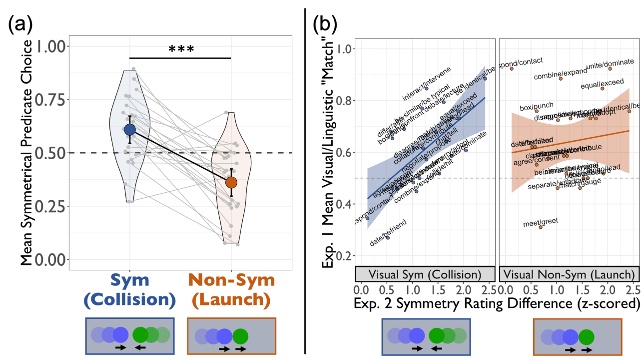

Figure 2: (a) Experiment 1 results. Participants matched symmetry across predicates and visual events. Item means ±95% CIs (within-item error bars). *** $p < .001$. *(b)* The difference in predicate symmetry ratings (Exp. 2) predicted the Exp. 1 "matching" effect, moreso for symmetrical visual events ($p < .001$) than non-symmetrical events ($p = .58$), with a marginal interaction between the two ($p = .106$).

Results

Our prediction was confirmed: As can be seen in Figure 2A, when participants viewed visual events that were symmetrical, they more often selected an English predicate with a logically symmetrical meaning (e.g., "equal" or "meet") than when they saw a visually non-symmetrical event, $\chi^2(1) = 19.90$, $p < .001$ (a main effect of Visual Type). In other words, symmetry across domains was "matched" together in the minds of our participants. This was also evident non-parametrically: 50/55 participants and 21/24 predicate pairs went in the direction of this effect. Moreover, the effect was stable throughout the experiment: there was no interaction between Visual Type and Trial Number, $\chi^2(1) = 0.31$, $p = .58$.

Remarkably, this effect was true regardless of the concreteness of the predicate pair. As can be seen in Table 1, predicates varied from highly abstract (e.g., "to differ") to highly concrete and observable (e.g., "to box"). However, average concreteness of the predicate pair was not a predictor of the magnitude of the matching effect, $\chi^2(1) = 1.16$, $p = .28$ (concreteness norms from Brysbaert et al., 2014).[4] Thus, people tended to choose symmetrical predicates for symmetrical visual events whether the predicates referred to an easily observable event or situation (e.g., "tango") or not (e.g., "agree").

[3] The random effects structure in all analyses was the maximal structure that converged, with random intercepts and random slopes by both participants and items (predicate pairs).

[4] In fact, the effect of concreteness trended in the opposite direction: the higher the average concreteness of the predicate pair, the *lower* the matching effect ($\beta = -0.16$, *s.e.* $= 0.15$, $z = -1.09$).

Experiment 2: Symmetry Ratings

Next we collected ratings of the symmetry of predicates and related these to the matching effect of Experiment 1. If the effect was driven by construal of symmetrical predicates as such, we should observe that symmetry ratings predict the degree to which participants matched a symmetrical predicate to a symmetrical visual stimulus.

Participants

32 participants were recruited from MTurk. Seven of these participants were excluded for low catch-trial performance. Demographic factors were the same as in Experiment 1.

Stimuli, Design, and Procedure

Stimuli were the 48 predicates from Experiment 1. Participants were instructed to rate how symmetrical each predicate was (one at a time), from 1 to 6. Participants were told a word is symmetrical if its meaning is "mutual". They were given contrasting examples for explanation ("cousin" vs. "father"; "next to" vs. "on top of").

Analysis

Symmetry ratings for each predicate were *z*-scored within-participant and then averaged across participants. The key measure was a "symmetry rating difference" for each predicate pair: the difference in average symmetry rating between a symmetrical predicate and its yoked non-symmetrical counterpart.

To test how well symmetry ratings predicted the "matching effect", we used the symmetry rating difference as a predictor in mixed effects logistic regression on trial-level data from Experiment 1. Specifically, the dependent variable was "match choice": choosing the predicate that matched the symmetry of the visual stimulus ("symmetrical choice" for visual symmetry trials, and "non-symmetrical choice" for visually non-symmetrical trials). Independent variables were Visual Type (symmetrical vs. non-symmetrical, sum-coded) and Symmetry Rating Difference (centered). We predicted a main effect of Rating Difference.

Results

First, ratings confirmed that across predicate pairs, our symmetrical predicates are conceived of as more symmetrical than their non-symmetrical counterparts. All pairs had a positive *z*-scored Symmetry Rating Difference (M=1.23, SD=0.56), ranging from "correspond"/"contact" (0.12) up to "be identical"/"be inferior" (2.42).

As predicted, the difference in symmetry ratings correlated with the matching effect: a model with the additional factor of Symmetry Rating Difference was a better fit than one with only a main effect of Visual Type, $\chi^2(1) = 11.69$, $p < .001$.

Surprisingly, as can be seen in Figure 2B, this relationship was stronger for collisions than launches: we observed a marginal improvement of a model with the interaction of Symmetry Rating Difference and Visual Type over one without this interaction, $\chi^2(1) = 2.61$, $p = .106$. In separate analyses on each visual type, we found that for collision trials, a model with Rating Difference was a significantly better fit than one without ($\chi^2(1) = 13.14$, $p < .001$), while this was not the case for launch trials ($\chi^2(1) = 0.31$, $p = .58$).

Our interpretation of this difference between visual types is the following (which we note is necessarily speculative). We suspect that when observers view visually symmetrical stimuli such as those in Experiment 1, these stimuli inextricably evoke a notion of symmetry. This makes symmetry available and salient as a dominant factor for matching, beyond the other rich semantic information these predicates also convey. By contrast, non-symmetrical visual stimuli do not strongly evoke symmetry (or even absence of symmetry), leaving other properties available for matching.

Experiment 3: One vs. Two Static Objects

Experiment 1 demonstrated that a correspondence exists between logically symmetrical predicates and visual stimuli, and Experiment 2 showed via symmetry ratings that this correspondence was driven by symmetrical construal per se (in both language and vision). What is the nature of this cross-domain correspondence?

In particular, first we asked whether dynamic stimuli such as the visual events of Experiment 1 are necessary to elicit such correspondence. There is reason to think not. After all, logically symmetrical predicates refer not just to events (e.g., “to box”, “to collide”), but also to states (e.g., “to match”, “to differ”). Likewise, the visual symmetry of static figures is a core property extracted automatically in visual processing (for review, see Wagemans, 1997).

Second, we asked whether construal of the visual stimulus as a binary relation between entities (i.e., “relational symmetry”) makes such correspondence more salient. There are reasons to think it might. Recall that in language, symmetry is a property of binary relations: i.e., relations holding between two *discrete entities*. It turns out that certain visual processes such as attention also operate over discrete entities — visual objects — and not just over features (e.g., edges, parts) or spatial regions (for review, see Scholl, 2001). Remarkably, this even extends to perception of certain relations: For example, chasing is better detected when it occurs between discrete objects rather than object *parts* (van Buren et al., 2017) — even though such parts can be *cognitively* construed as discrete entities. Indeed, the visual events of Experiment 1 occurred between two objects and elicited a strong matching effect.

Here we asked whether the visual/linguistic symmetry correspondence extends to static objects that convey symmetry, and we tested whether such correspondence is stronger for two discrete visual objects, where perceptual accessibility of the relation’s binary nature is more salient.

Participants

100 participants were recruited from the online platform Prolific. Demographic factors and exclusion criteria were the same as in Experiment 1 (one participant was excluded).

Stimuli

Linguistic stimuli were the predicate pairs from Experiment 1. Visual stimuli were simple objects constructed using similar methods to Baylis and Driver (2001). Objects were eight rectangular blocks (pseudorandom width) connected adjacently, top to bottom. Each object was surrounded by a black border and was placed with a slight shadow on a textured background; together these cues bias interpretation of the objects as figure rather than ground. Objects were filled in red, green, or blue. Examples appear in Figure 1C.

Two factors were crossed in this experiment. First, visual stimuli were either symmetrical or non-symmetrical. Second, visual stimuli were either one or two objects. For single symmetrical objects, rectangular blocks were mirror-reflected about the vertical axis. Two-object versions of each single object were created by making two differently-colored objects face each other with the same center-facing contour as the contour of the single symmetrical object. Non-symmetrical versions of each stimulus were made by offsetting 75% of the blocks horizontally by a pseudorandom amount.

Design, Procedure, and Analysis

Design, procedure, and analysis were similar to Experiment 1, but with one additional factor: Object Number (One or Two). There were two blocks of 12 trials: a One-Object block and a Two-Object block (Block Order counterbalanced across participants). Within-block, trials were evenly divided between Symmetrical and Non-Symmetrical visual stimuli (trial order randomized). Block Order (sum-coded) was included as an additional factor in model comparison. Images were displayed at 536x402px for 2784ms, preceded by a 350ms fixation cross.

Once again, the key prediction was a significant “matching” effect, i.e., for symmetrical choices to be higher for visually symmetrical vs. non-symmetrical stimuli (which would manifest as a main effect of Visual Type). We also predicted an interaction between Visual Type and Object Number, whereby the “matching” effect for the Two Objects condition would be greater than the One Object condition.

Results

Data appear in Figure 3. First, as in Experiment 1, participants matched symmetrical predicates to symmetrical visual stimuli more often than to non-symmetrical visual stimuli, $\chi^2(1) = 13.24$, $p < .001$ (a main effect of Visual Type). Confirming our second prediction, the matching effect was stronger for Two-Object than One-Object trials. This manifested as a significant interaction of Visual Type and Object Number, $\chi^2(1) = 4.76$, $p = .029$ (compared to a model with only main effects of these factors).

Finally, there were no order effects: the Two-Object advantage for the matching effect held whether participants viewed the One-Object or Two-Object block first (no significant interaction of Block Order, Visual Type, and Object Number, $\chi^2(3) = 0.84$, $p = .84$). This suggests that by default the mind analyzes two symmetrically configured visual objects in terms of a binary relation, which can then more readily be associated with symmetrical predicates.

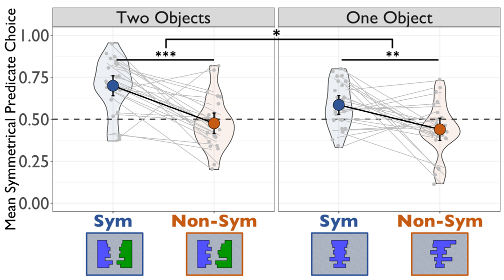

Figure 3: Experiment 3 results. Participants matched symmetry across predicates and static objects, moreso for two objects than one. Item means ±95% CIs (within-item error bars). *** $p < .001$; ** $p < .01$; * $p < .05$.

General Discussion

Our studies show that the abstract property of symmetry is represented and placed into correspondence across cognitive systems, and reveal several aspects of its nature. First, individuals have access to the formal property of symmetry for predicates. Second, individuals are sensitive to visual cues to symmetry. Third, the commonality in symmetry across vision and language is intuitive, such that individuals in our studies associated symmetrical items across these two domains. This was true even though the predicates (e.g., "equal", "differ") did not in general relate transparently to the visual stimuli — nor indeed to visual concepts at all.

We also identified the generality of this mapping, and some of its constraints. It held not only for dynamic events (Exp. 1), but also static figures (Exp. 3). Furthermore, making the visual stimuli's binary nature less apparent (as in Exp. 3, single objects) weakened the ability to recognize this correspondence. Apparently, symmetry across cognitive systems is most obvious when it is "relational", i.e., when it holds for a binary relation, in both cases. This finding is consistent with previous work showing qualitative differences in processing within- and between-object symmetry (Baylis & Driver, 2001; Shao & Gentner, 2019).

Perceived Symmetry?

A stimulus being visual does not on its own entail that all of its high-level properties (such as symmetry) are perceived via rapid, automatic visual processes. Instead, one might infer the property by *reasoning* over more basic visual features, such as contours or motion trajectories. Is the visual symmetry for cross-domain correspondence inferred via higher-level cognitive processes, or genuinely *perceived* (Hafri & Firestone, 2021)? This is a crucial question, as it would reveal whether perception itself may automatically furnish symmetry for observed situations, which could be utilized for other cognitive processes such as word-learning. Our data in Experiment 2 may suggest as much: The symmetry rating difference between paired predicates predicted the matching effect for symmetrical visual events (collisions), but less so for non-symmetrical ones (launches). This suggests that visually symmetrical events made linguistic symmetry especially salient in the mind. Future work may confirm and enrich this conclusion.

Implications for Learning Symmetrical Predicates

Despite the ubiquity of symmetry in natural language, surprisingly little is known about how children acquire it. As Gleitman et al. (2019) showed with the spontaneous emergence of symmetry in NSL, the abstract notion of symmetry is *available* to the mind, even before knowledge of individual symmetrical lexical items develops. Thus, this is at its core a mapping problem: discovering which phonological forms encode which (abstract) meanings.

How does this knowledge develop? For highly abstract words, observation alone, however sophisticated, cannot be sufficient. Nonetheless, our results, if they generalize to young children, suggest one possible learning story: There might exist perceptual "gems" for observable symmetrical situations (e.g., shaking hands, hugging) that could enable the child to acquire more concrete symmetrical words, if they happen to be uttered in such contexts.[5] Children could then use knowledge of the syntactic structures of these learned symmetrical items to acquire more abstract ones: so-called syntactic bootstrapping (Gleitman, 1990; Yuan et al., 2012).

The ultimate solution will certainly prove complex, as symmetricals pose a unique challenge for acquisition via syntactic-distributional evidence: There is no one structure (in English) unique to logical symmetry (examine examples (1) to (5)). Nevertheless, we suggest that such a route is a fruitful avenue for future research.

Concluding Remarks

The property of symmetry goes far beyond sensory experience, to social situations (e.g., *marry, meet*) and even to the abstractions pervasive in scientific reasoning (e.g., *equal, similar*). Our findings support the existence of an abstract relational concept of symmetry which humans access via both perceptual means (from certain observable events or situations) and linguistic means (from terms referring to symmetrical concepts). More broadly, this work sheds light on the rich, structured nature of the language-cognition interface, and points towards a possible avenue for acquisition of word-to-world mappings for the seemingly inaccessible logical symmetry of linguistic terms.

[5] In ongoing work, we have generalized our paradigm to ASL signs that iconically represent symmetry but otherwise differ in myriad ways. This suggests that our proposal is plausible even for rich naturalistic visual stimuli.

Acknowledgments

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