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► **To cite this version:**

Thomas Chartier, Arnaud R Rey. Is symmetry inference an essential component of language?. Learning and Behavior, 2020, 48 (3), pp.279-280. 10.3758/s13420-019-00405-5 . hal-02943216

HAL Id: hal-02943216

<https://hal.science/hal-02943216>

Submitted on 12 Nov 2020

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1 Manuscript for Learning & Behavior: *Outlook* section

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3 **Is symmetry inference an essential component of**
4 **language?**

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16 **Keywords:** Associative learning; symmetry inference; preverbal humans;

17 language evolution

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19 **Summary:**

20 Symmetry inference, i.e. spontaneously deriving the stimulus association B-A from

21 A-B, was recently reported in preverbal infants (Kabdebon & Dehaene-Lambertz,

22 2019) and regarded as a “building block for human cognition”. Here we argue that

23 empirical evidence supporting this claim is insufficient, and that absence of

24 symmetry inference in non-human animals should be reassessed.

25 Main Text

26 Bidirectional associations are a central feature of human language, as they
27 permit a flexible and interchangeable use between spoken, written or sign words,
28 and representations of the objects referred to. For example, one can both think
29 about a dog upon hearing 'dog', and say 'dog' upon thinking about one. While such
30 symmetrical associations are easily conceived as arising from a bidirectional
31 training, as happens when parents repeatedly name and show a given object to a
32 child, human adults or children trained on successive stimulus pairings A-B have
33 been reported to spontaneously derive the reversed, untrained relations B-A, i.e.
34 to infer bidirectional associations from unidirectional ones (e.g. Sidman et al.,
35 1982). This capacity, called *symmetry inference*, has proved highly difficult to
36 demonstrate experimentally in non-human animals (e.g. Medam, Marzouki,
37 Montant, & Fagot, 2016) and could thus be unique to people. Such findings have
38 raised strong interest as to the potential necessity of symmetry inference for
39 language to develop, making it the marker of a potential discontinuity between
40 human and non-human behavior.

41 However, because symmetry inference means disregarding the order of
42 elements that are associated, one can argue that such propensity can be
43 detrimental, as it may break naturally occurring causal regularities and induce
44 maladaptive behaviors. In this view, it is expected that non-human animals do not
45 show symmetry inference, and surprising that humans do; such cognitive bias in

46 humans might simply emerge together with language development, as a by-
47 product of our constant use of bidirectional associations.

48 A strong argument in favor of symmetry inference being required for
49 language would be to find it in preverbal humans. A recent PNAS article
50 (Kabdebon & Dehaene-Lambertz, 2019) has reported such results. Using EEG
51 recordings, the authors tested the ability of 5-month-old infants to abstract
52 representations from patterns of trisyllabic spoken non-sense words (e.g. ‘ba-ke-
53 tu’) and associate these representations with visual or auditory labels (e.g. a lion
54 picture). In their critical Experiment 3, upon testing 34 infants with reversed pairs,
55 i.e. presenting them with label-pattern pairs after a pattern-label training, the
56 authors observed different brain activities depending on whether reversed pairs
57 were consistent or inconsistent with initial pairings. They interpret this as evidence
58 that infants expected the second stimuli (the patterns) consistently with training,
59 meaning that they had inferred symmetrical associations from unidirectional ones.
60 The authors view this ability as ‘*a foundational operation for any symbolic system*’,
61 and, arguing that other animals do not have it, they suggest that it constitutes ‘*a*
62 *building block for human cognition and notably language development*’,
63 distinguishing humans from non-humans. We would like to argue that both
64 arguments supporting this claim, namely that preverbal humans can infer
65 symmetry, and that non-humans cannot, are insufficiently grounded.

66 First, the data interpretation in their study is certainly debatable. Contrary to
67 their claim, a careful inspection of the experimental design reveals that the trained
68 associations were already bidirectional and consequently, infants did not need to

69 infer symmetry. The flaw, present in all three experiments, was two-fold. During
70 the training period, infants were not exposed to well separated pattern-label pairs,
71 but with a regularly alternating sequence of word patterns and labels. Indeed, and
72 surprisingly, the inter-trial stimulus interval (ITI = 733 ms) was comparable to the
73 within-trial stimulus interval (980 ms). Consequently, infants experienced a similar
74 temporal contiguity for the backward associations label-pattern between two
75 consecutive pairs as for the forward associations pattern-label of each pair, and
76 had the opportunity to learn both types of relations. The artificial separation of trials
77 by a distracting visual stimulus (the blinking eyes) could not prevent such learning
78 from taking place, as infants are known to be particularly sensitive to statistical
79 structure in temporal sequences. This need not have been a problem, had a given
80 label not systematically been followed by the same word pattern. Yet, precisely
81 this happened, as pairs were repeated in 12 consecutive trials (see their
82 Supplementary Material p.5). To illustrate, if one calls P and Q the word patterns
83 and X and Y the labels, infants were effectively first exposed to PXPXPX...PX (12
84 times) then QYQYQY...QY (12 times), i.e. almost as many reversed instances of
85 the consistent pairs (XP and YQ, 11 times) as forward instances (PX and QY, 12
86 times). The subsequent randomized presentation of pairs was too brief to correct
87 for the statistical structure already introduced: PX and QY each randomly
88 appearing 6 times yielded exposition to reversed consistent (XP and YQ) and
89 reversed inconsistent (XQ and YP) pairs, both on average 3 times, and at most 6.
90 Consequently, not only were infants explicitly exposed to reversed pairs before
91 testing, but this happened with more consistent ones (around 14 times) than

92 inconsistent ones (around 3 times). Not surprisingly, when the test was performed
93 (Experiment 3), a differential brain response was detected between consistent and
94 inconsistent reversed pairings. The data thus only reveal a simultaneous learning
95 of several conditional associations and do not allow us to conclude that 5-month-
96 old infants can infer symmetry. Adequate experiments would require a
97 familiarization phase with a longer ITI and a fully randomized presentation of pairs.

98 No other study, to our knowledge, has searched for symmetry inference in
99 preverbal humans, hence the important question of whether such capacity
100 develops before language use remains unanswered. To address it, investigations
101 in preverbal infants are crucial, because symmetry inference in verbal subjects is
102 easily accounted for in terms of verbal recoding. Since human subjects readily
103 name experimental stimuli, the phonological loop is likely used, which naturally
104 transforms unidirectional associations into bidirectional ones.

105 Second, despite plentiful negative results, some words of caution are
106 needed before asserting that symmetry inference is only observed in humans. A
107 familiarity with symmetry, as verbal humans always have, may simply be needed.
108 Indeed, one study including a *symmetry training* on a subset of stimulus pairs
109 revealed symmetry inference in a sea lion (Schusterman & Kastak, 1993). Besides,
110 to our knowledge, symmetry inference in humans was never demonstrated with a
111 strictly unidirectional training. All studies (e.g. Sidman et al., 1982) have used
112 *identity training*, i.e. have included identical pairs A-A and B-B alongside arbitrary
113 pairs A-B, to avoid the surprise effects of seeing items A and B in new ordinal
114 positions during the test with B-A. Adding such training in pigeons also yielded

115 evidence for symmetry inference (Frank & Wasserman, 2005). Hence, at least two
116 experimental conditions promote symmetry inference in non-humans, one of which
117 may even be required in humans. Furthermore, all studies so far have looked for
118 a spontaneous motor output exemplifying the reversed stimulus pairings. But it
119 might be that animal subjects do infer symmetry, though for some reason they do
120 not show *explicit* signs of it. Consequently, *implicit* signatures of symmetry
121 inference, for example, a faster learning of reversed pairs compared to arbitrary
122 pairs, should also be looked for. The purported absence of symmetry inference in
123 non-human animals should thus be reassessed, with new comparative
124 experiments examining the influence of both symmetry training and identity training
125 on symmetry inference, and including implicit tests.

126 Clarifying both major questions – whether symmetry inference is found only
127 in humans and whether it develops before language – will lead to one of four
128 outcomes. 1) If it is indeed absent in non-humans and present in preverbal
129 humans, as speculated in the PNAS study, then it could constitute a key
130 prerequisite for language. Yet, proving that it is required would still be difficult, as
131 one would typically need to somehow suppress this ability and show that language
132 development is impaired. 2) If both non-humans and preverbal humans can infer
133 symmetry, then it could still represent a crucial, though not sufficient, building block
134 of language. 3) If symmetry inference is unique to humans and develops only after
135 language, it would simply be a bias stemming from language, allowing for logically

136 wrong inferences. 4) If instead it is shared with non-humans, though this is less
137 likely, it would be a capacity independent of language.

138 Finally, it is probably important to distinguish between *inferential* and
139 *processing* abilities. Non-human animals may be unable to infer reverse
140 associations they have not experienced, while nevertheless using bidirectional
141 associations which they would learn through simultaneous stimulus exposure, i.e.
142 through bidirectional, not unidirectional training.

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172 (1490 words)