Behavioural Processes 83 (2010) 99–112

Contents lists available at ScienceDirect

Behavioural Processes

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

Nonverbal transitive inference: Effects of task and awareness on human performance

Olga F. Lazareva[a,*], Edward A. Wasserman[b]

[a] Department of Psychology, Drake University, 316 Olin Hall, Des Moines, IA 50311-4505, United States
[b] Department of Psychology, University of Iowa, Iowa City, IA 52240-1515, United States

ARTICLE INFO

Article history:
Received 6 April 2009
Received in revised form 30 October 2009
Accepted 4 November 2009

Keywords:
Transitive inference
Learning
Awareness
Deductive reasoning
Associative models

ABSTRACT

We studied human nonverbal transitive inference in two paradigms: with choice stimuli orderable along a physical dimension and with non-orderable choice stimuli. We taught 96 participants to discriminate four overlapping pairs of choice stimuli: A+ B−, B+ C−, C+ D−, and D+ E−. Half of the participants were provided with post-choice visual feedback stimuli which were orderable by size; the other half were not provided with orderable feedback stimuli. In later testing, we presented novel choice pairs: BD, AC, AD, AE, BE, and CE. We found that transitive responding depended on task awareness for all participants. Additionally, participants given ordered feedback showed clearer task awareness and stronger transitive responding than did participants not given ordered feedback. Associative models (Wynne, 1995; Siemann and Delius, 1998) failed to predict the increase in transitive responding with increasing awareness. These results suggest that ordered and non-ordered transitive inference tasks support different patterns of performance.

Inferring that "b is related to d" from the premises "b is related to c" and "c is related to d" requires *transitive inference*, a phenomena related to deductive reasoning. A transitively competent individual should infer that "b is related to d" from the two trained relations, if and only if the relation in question is transitive. Many, but not all, relations support transitive inference (TI). For example, from the premises "Anna is taller than Mary" and "Mary is taller than Bob," it follows that "Anna is taller than Bob." But, no such derivation follows from the premises "Anna likes Mary" and "Mary likes Bob," because the relation "to like" is not transitive (Evans et al., 1993; Markovits and Dumas, 1992; Wright, 2001).

Children younger than 8 years of age often attempt to derive transitive-like inference from non-transitive relations, suggesting that the ability to discriminate verbal terms that allow valid inference (such as "taller" or "older") from those that do not (such as "love") may emerge gradually (Kuszaj and Donaldson, 1982). Moreover, Goodwin and Johnson-Laird (2008) demonstrated that, although adults can successfully discriminate transitive and non-transitive relations, they often attempt to derive transitive-like inferences from pseudo-transitive or ill-defined terms that may or may not lead to correct inference. For example, the premises "Anna is a blood relative of Mary" and "Mary is a blood of relative of Bob" often leads to the inference that "Anna is a blood relative of Bob." Yet, this inference is only correct if the relationship in question is that of siblings or linear descendants; if Anna is Mary's mother and Bob is her father, then Anna and Bob are not blood relatives. In other words, even adult humans may sometimes make invalid inferences. The distinction between relations that afford valid inferences and those that do not is thus an important factor in human verbal deductive reasoning.

1. Theories of verbal TI

Several theories have attempted to explain deductive reasoning, including TI, in verbal settings (see Goodwin and Johnson-Laird, 2005; Johnson-Laird, 1999, for detailed reviews). Some of these theories describe TI as an exclusively linguistic process (e.g., Clark, 1969) and therefore one that cannot easily be extended to nonverbal settings. Here, we will concentrate on those theories that may apply in both verbal and nonverbal settings.

Spatial array theory (De Soto et al., 1965) proposes that people first construct a unitary mental representation of the situation described in the premises and then use this representation to make transitive inferences. For example, given the premises "Anna is taller than Mary" and "Bob is shorter than Mary," people construct the ordered series Anna > Mary > Bob and then use this series to perform transitive inferences. Mental model theory (Goodwin and Johnson-Laird, 2005) postulates that people use the information given in the premises and their general knowledge to construct a single mental model of a situation. Hence, a person

* Corresponding author. Tel.: +1 515 271 4801; fax: +1 515 271 1925.
E-mail address: olga.lazareva@drake.edu (O.F. Lazareva).

0376-6357/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.beproc.2009.11.002

may make an invalid transitive inference from pseudo-transitive terms (see the example above) if he or she mistakenly constructs a model that does not fully represent the situation given in the premises.

Regardless of the particular theory, research on verbal TI has shown that, when more than two premises are given, people do not memorize the individual premises. Instead, they integrate these premises into an ordered series and then use this series to find the answer to the test questions (Byrne and Johnson-Laird, 1989; Goodwin and Johnson-Laird, 2008; Maybery et al., 1986; see Evans et al., 1993 for a review). This observation suggests that we ought to observe symbolic distance effects in verbal transitive inference similar to those observed in nonverbal transitive inference; to some extent, this prediction has been confirmed in several studies (Byrne and Johnson-Laird, 1989; Maybery et al., 1986).

2. Semi-verbal and nonverbal techniques to study TI

Early research into human TI used verbal or written syllogisms, as in the above examples. Work by Piaget (1965) found that children younger than 7 years of age were unable to solve such tasks. Later, Bryant and Trabasso (1971) suggested that the failure to find TI in young children might be related to their inability to remember the verbal premises rather than to the absence of an inferential ability. Consequently, these researchers developed a semi-verbal method of testing children's TI ability.

Bryant and Trabasso used pairs of wooden sticks of different colors extending an *equal* distance above the top of a box. Only after a child had reported which stick was longer or shorter did the investigators show the child the *full* lengths of both sticks by taking them out of the box. The lengths of sticks, therefore, provided visual feedback *after* the choice was made. Therefore, just as in the verbal task, the choice items in this task could be ordered along a physical dimension, length, which supported a transitive relation between them. Bryant and Trabasso presented four pairs of items: A+ B−, B+ C−, C+ D−, and D+ E− (where the letters represent different visual stimuli and the plus and minus signs indicate that choice of the corresponding visual stimuli was rewarded or nonrewarded, respectively). In another experiment, the children were never shown the full lengths of the sticks, but they were instead told which stick was longer and which stick was shorter; in other words, the visual feedback was replaced by verbal feedback.

To test for TI, the novel BD testing pair was presented. This pair involved stimuli that were never before presented together and that had each appeared in one pair as a rewarded stimulus and in another pair as a nonrewarded stimulus. A transitively competent individual was expected to remember that B > C and C > D, to infer that B > D, and to select B over D. Bryant and Trabasso found that 4-year-old children were quite able to select the transitively correct B stimulus when the discrimination task was presented in semi-verbal form.

Further research by Trabasso and Riley (Riley, 1976; Riley and Trabasso, 1974; Trabasso et al., 1975) also implied that children perform the TI task by arranging the visual stimuli into an ordered series during training and that they find the correct answer for the novel pair during testing by accessing this array. In other words, when taught the premises A > B, B > C, C > D, and D > E, people construct the ordered series A > B > C > D > E, which is later used to select the correct stimulus in any novel pair. Note that this strategy is quite similar to the strategy used in verbal TI settings with more than two premise pairs.

The semi-verbal technique developed by Bryant and Trabasso (1971) was later modified to be entirely nonverbal and then used to study transitive responding in both nonhuman animals (see Delius and Siemann, 1998; Vasconcelos, 2008, for a review) and people (e.g., Acuna et al., 2002; Greene et al., 2001; Leo and Greene, 2008; Libben and Titone, 2008; Martin and Alsop, 2004; Siemann and Delius, 1996; Siemann and Gebhardt, 1996; Smith and Squire, 2005). The animal studies were inspired by the human research; but, the facts uncovered in the realm of animal transitivity later affected the study of nonverbal transitive inference in people. We now turn to an analysis of the animal research.

3. Animal research: Associative theories of transitive responding

Transitive responding in animals has been studied with two different paradigms. In some animal studies, the relation between the stimuli is explicitly given as a difference in weight, height, or area (Lazareva et al., 2004; Lazareva and Wasserman, 2006; McGonigle and Chalmers, 1977; Rapp et al., 1996; Roberts and Phelps, 1994; Treichler and Van Tilburg, 1996), just as Bryant and Trabasso did. We call this design the *ordered* TI task. In other animal studies (Boysen et al., 1993; Davis, 1992; Dusek and Eichenbaum, 1997; MacLean et al., 2008; Paz-y-Mino et al., 2004; Siemann et al., 1996; Steirn et al., 1995; von Fersen et al., 1991), the stimuli themselves were arbitrary, but the researchers hypothesized that their animal participants might establish a transitive relation among them purely on the basis of reward or nonreward; we call this design the *non-ordered* TI task.

Note that the relations "reinforced" or "nonreinforced" are binary: as long as there is no difference in the magnitude of reinforcement, there seems to be no basis for dimensionally ordering such stimuli (Markovits and Dumas, 1992; Wright, 2001). On the other hand, a discrimination procedure such as this may establish a preference for one stimulus over the other and such *preferences* may be transitive. In fact, value transfer theory (von Fersen et al., 1991) as well as other associative theories applied to the TI problem suggest that the relation becomes transitive during training, as an ordered series of associative values emerges.

In general, associative theories of TI suggest that TI is possible and valid because of reinforcement history. According to those models, all of the stimuli before training have the same associative values; therefore, there is no reason to prefer stimulus B over stimulus D. As training proceeds, each stimulus choice that is followed by reinforcement leads to an increase in the associative value of that stimulus. Similarly, each stimulus choice that is not followed by reinforcement leads to a decrease in the associative value of that stimulus. Ultimately, training with the pairs A+ B−, B+ C−, C+ D−, and D+ E− results in an ordered series of associative values: A > B > C > D > E (see reviews by Delius and Siemann, 1998; Vasconcelos, 2008; Wynne, 1995, 1997, 1998 for more details). Thus, a subject could choose stimulus B over stimulus D based on their relative associative values instead of using inferential-like processes. This view also implies that there is no fundamental difference between transitive, pseudo-transitive, and non-transitive inferences: if the reinforcement history leads to an ordered series of associative values, then the inference will be made regardless of the nature of the relationship among the stimuli. This and other considerations has led some authors to propose that reinforcement-based transitive inference ought to be termed pseudo-transitive (e.g., Markovits and Dumas, 1992; Moses et al., 2008).

Value transfer theory, the first in this class of models, proposed that the associative values of the training stimuli produce an ordered series, A > B > C > D > E, due to bidirectional transfer of associative value between the reinforced and nonreinforced stimuli (von Fersen et al., 1991). Later studies revealed, however, that an ordered series of associative values arises even when no transfer of values across stimuli is postulated (see Siemann and Delius, 1998; Wynne, 1995, 1998 for more details).