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Understanding Complex Behavior: The Transformation of Stimulus Functions

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The transformation of stimulus functions is said to occur when the functions of one stimulus alter or transform the functions of another stimulus in accordance with the derived relation between the two, without additional training. This effect has been demonstrated with a number of derived stimulus relations, behavioral functions, experimental preparations, and subject populations. The present paper reviews much of the existing research on the transformation of stimulus functions and outlines a number of important methodological and conceptual issues that warrant further attention. We conclude by advocating the adoption of the generic terminology of relational frame theory to describe both the derived transformation of stimulus functions and relational responding more generally.

Key words: transfer and transformation of stimulus functions, derived stimulus relations, stimulus equivalence, relational frame theory, adults and children

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Understanding the emergence of behavior for which an explicit history of reinforcement is either extremely remote or obviously lacking has often represented a challenge for behavioral analyses of complex behavior. Recently, however, behavior analysts have shown considerable interest in the research area of derived stimulus relations, which, many argue, may provide the foundations for a behavioral account of novel behavior. Typically studied using a matching-to-sample (MTS) procedure, the basic finding is as follows. Suppose, for instance, reinforcement is delivered for selection of Comparison B in the presence of the Sample A and for selection of Comparison C in the presence of Sample B. Most verbally able humans will readily reverse these explicitly reinforced conditional discriminations in the absence of further training. That is, they will select A given B and B given C in accordance with derived symmetrical, or mutually entailed, stimulus relations. Furthermore, subjects will also select C given A and A given C in accordance with derived transitive and equivalence, or combinatorially entailed, stimulus relations without further training. Following such derived performances, the stimuli are said to participate in an equivalence class (Sidman, 1994) or a relational frame of equivalence (Barnes, 1994; S. C. Hayes, 1991). Perhaps what is most interesting about derived stimulus relations such as equivalence is that the test outcomes are not readily predicted from the traditional concept of conditional discrimination; neither A nor C has a direct history of differential reinforcement with regard to the other, and, therefore, neither stimulus should control selection of the other.

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Another feature of derived stimulus relations is the transformation of stimulus functions, which has also generated research interest due in part to its implications for understanding a wide range of complex derived behavior. The transformation of stimulus functions occurs when the function of one stimulus in a derived relation alters the functions of another according to the derived relation between the two, without additional training (Dougher & Markham, 1994, 1996; S. C. Hayes, 1991). As a practical example of the transformation of functions, consider an individual who derives an equivalence relation consisting of the spoken word "stop," a stop sign, and a gesture from a crossing guard to stop. Later, she may learn that when her teacher says "stop," it is time to stop and wait for oncoming traffic. Subsequently, the stop sign and the crossing guard's gesture may occasion similar behavior on the part of the individual. This transformation of functions is based on the behavioral function of "stop" and the derived relation between the spoken word and the gesture or the sign.

To date, an increasing number of stimulus-function transformations have been studied in several laboratories using a number of different procedures and subject populations. Several authors have argued that these studies may have implications for contemporary behavior-analytic accounts of, for instance, self-awareness (Dymond & Barnes, 1997a), stereotyping (Kohlenberg, Hayes, & Hayes, 1991), dreaming (Dixon & Hayes, 1999), sexual arousal (Roche & Barnes, 1997), emotional disorders (e.g., Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Friman, Hayes, & Wilson, 1998; S. C. Hayes & Wilson, 1993), moral behavior (Hayes, Gifford, & Hayes, 1998), rule following (e.g., Barnes-Holmes, Healy, & Hayes, 2000; S. C. Hayes, Gifford, & Ruckstahl, 1998), and verbal behavior (e.g., S. C. Hayes & Hayes, 1992). In effect, the transfer of functions may have implications for a functional approach to verbal behavior. Consider the following. The individual's behavior in the example outlined above is likely to come under the control of both the stop sign and the gesture from a crossing guard by virtue of the fact that these stimuli participate in an equivalence relation with the word "stop." Thus, the functions of the stop sign and the gesture are "discriminative-like," because all the relevant functions are derived. That is, they are functioning as *verbal stimuli* (Dymond & Barnes, 1997a, pp. 189–190; S. C. Hayes, Gifford, & Wilson, 1996; S. C. Hayes & Wilson, 1993). *According to this view, verbal stimuli are those that participate in derived stimulus relations and that have their functions based, in part, on the transfer of functions.* If, instead, the child had a direct history of reinforcement for stopping in the presence of both the stop sign and gestures from the crossing guard, then these stimuli would be functioning as a discriminative stimuli and the performance would be entirely nonverbal. In sum, the implications indicate that the transfer of functions may provide the foundation through which stimuli acquire novel functions, both adaptive and aberrant, through verbal means. Clearly, much is at stake in the study of derived stimulus relations and the transformation of stimulus functions.

The purpose of the present paper is to review the research conducted to date on the transformation of stimulus functions in accordance with symmetry, equivalence, and other derived relations. In doing so we will highlight a number of methodological issues that warrant further empirical study. Then, in the final section, we will outline our reasons for adopting the generic terminology of relational frame theory to describe the derived transformation of stimulus functions. Two caveats are necessary, however, before we begin. First, this review is by no means exhaustive; other reviews have been published that take a somewhat different approach to many of the phenomena discussed in the present paper (see

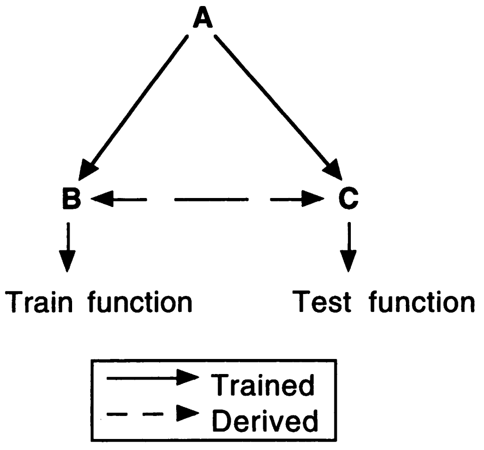

Figure 1. A schematic representation of the design of a typical transfer-of-function study. See text for details.

Dougher & Markham, 1994, 1996). Second, the majority of the relevant research conducted to date has been discussed in terms of the *transfer*, rather than the transformation, of functions. Descriptions of this work in the present paper will remain consistent with the original terminology up until our introduction of relational frame theory.

A Definition

Dougher and Markham (1996, p. 139) defined transfer of function as "the untrained acquisition or emergence of stimulus functions" that are "independent of the shared functions that define the class." That is, functions other than the conditional or discriminative functions of the class transfer from one class member to the remaining stimuli. For example, a series of conditional discriminations are trained and subsequently tested for derived equivalence relations (see Figure 1). Then a particular behavioral function is directly trained for one member of the relation (i.e., B), and following this, some or all of the remaining stimuli (i.e., C, A, etc.) are tested to see if they have acquired the function, without additional training (Figure 1). If the trained function has transferred to the remaining stimuli in the absence of further training, transfer of function is said to have occurred. This outcome is based on the trained function of B and the derived relation between B and at least one other stimulus.

Descriptions of transfer-of-function research usually make explicit mention of the derived stimulus relations involved in the transfer performance. In the example given above, if the trained function has transferred to the remaining stimuli in the absence of additional training, then a transfer of functions through equivalence relations is said to have occurred. Different researchers have used different terms to describe this outcome such as "transfer via equivalence," "transfer across members of an equivalence relation," or "transfer in accordance with equivalence relations." It is not the intention of the present paper to discuss the relative merits of these descriptions. The present paper will instead address the existing transfer-of-function research through derived stimulus relations of increasingly complexity, beginning first with derived symmetrical and equivalence relations and concluding with multiple stimulus relations such as sameness, more than, and less than.

TRANSFER OF FUNCTIONS THROUGH SYMMETRY

The transfer of functions through derived symmetrical relations has been demonstrated a number of times (Barnes & Keenan, 1993; Catania, Horne, & Lowe, 1989; de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; Dougher et al., 1994; Gatch & Osborne, 1989; Rehfeldt & Hayes, 1998b), and merits a discussion separate from our more general treatment of the transfer of functions through equivalence relations. Recent evidence has suggested that the relations comprising stimulus equivalence may differ systematically from one another (see Sidman & Tailby, 1982). For example, symmetry relations have been shown to be most sensitive to changes in baseline reinforcement contingencies (Pilgrim, Chambers, & Galizio, 1995; Pilgrim & Galizio, 1995; Saunders, Drake, & Spradlin, 1999) and are more likely to be maintained over time (Rehfeldt & Hayes, 2000). In addition, demonstrations of symmetry have been reported in the absence of transitivity and equivalence relations until many test trials have been presented (e.g., Bush, Sidman, & de Rose, 1989), and response latency has been shown to be shorter for symmetry test trials than for transitivity and equivalence test trials (Bentall, Dickins, & Fox, 1993; Spencer & Chase, 1996; Wulfert & Hayes, 1988). Subjects have also been shown to estimate a greater percentage of reinforcement for symmetry test trials than for transitivity and reflexivity test trials (Pilgrim & Galizio, 1996). Findings such as these suggest that the relations defining equivalence class membership may be construed as different operant units (see Pilgrim & Galizio, 1996; Roche, Barnes, & Smeets, 1997; Wilson & Hayes, 1996).

Consistent with these findings, it seems plausible that results indicative of a transfer of functions through symmetry relations may differ from a transfer of functions through equivalence relations. Stimuli that are related symmetrically are directly paired during training, whereas those that are related via equivalence have been only indirectly related. Due to this contiguous arrangement of the stimuli during training, it has been suggested that perhaps the transfer of function through symmetry relations should not be considered genuine derived control (e.g., Barnes & Keenan, 1993; Dougher et al., 1994). Comparing the effectiveness of function transfer between stimuli that are contiguously related during training and hence directly related, and between stimuli that have only been indirectly related, would be worthwhile to explore.

The transfer of functions through symmetry relations is important to consider for additional reasons. De Rose et al. (1988) found that stimulus functions transferred readily from conditional to discriminative stimuli in the MTS paradigm, but that transfer of functions in the opposite direction was not observed. In other words, the transfer of functions appeared to have occurred in *one direction only* (although the authors do note that differences in the number of training trials could have contributed to this finding; see de Rose et al., p. 168). These results suggest some similarities between the observation of transfer through symmetry relations and classical conditioning, which also occurs in one direction only (see L. J. Hayes, 1992; Rehfeldt & Hayes, 1998a). Future research directed at the role of contiguity, as well the development of new procedures (e.g., Cullinan, Barnes, & Smeets, 1997; Leader, Barnes, & Smeets, 1996), may help to further disentangle the relationship between symmetry and transfer of function.

TRANSFER OF FUNCTIONS THROUGH EQUIVALENCE

The transfer of functions through equivalence relations has been demonstrated with discriminative, self-discriminative, consequential, respondent eliciting, extinction, and sexual arousal stimulus functions in adults, children, and developmentally disabled individuals (e.g., Barnes & Keenan, 1993; de Rose et al., Dougher et al., 1994; Dymond & Barnes, 1994, 1997b, 1998; Fields, Adams, Buffington, Yang, & Verhave, 1996; Gatch & Osborne, 1989; Green, Sigurdardottir, & Saunders, 1991; Greenway, Dougher, & Wulfert, 1996; S. C. Hayes, Devany, Kohlenberg, Brownstein, & Shelby, 1987; Lazar, 1977; Roche & Barnes, 1997; Wulfert & Hayes, 1988). To illustrate, S. C. Hayes et al. (1987) first trained adults in two MTS conditional discriminations (i.e., if Sample A1, select Comparison B1 and not B2; if A2, select B2 and not B1; if A1, select Comparison C1 and not C2; if A2, select C2 and not C1). Subjects were then tested for the derivation of two equivalence relations (A1-B1-C1, A2-

B2-C2). Next, a stimulus from each equivalence relation was given a distinct, simple discriminative function; in the presence of B1, clapping was reinforced, and in the presence of B2, waving was reinforced. During testing, the discriminative functions assigned to the B1 and B2 stimuli transferred, through equivalence, to the C1 and C2 stimuli, in the absence of differential consequences for either clapping or waving in the presence of the test stimuli (i.e., B1 → clap transferred to C1 → clap, and B2 → wave transferred to C2 → wave).

METHODOLOGICAL ISSUES IN TRANSFER-OF-FUNCTION RESEARCH

Given the array of functions and methodologies employed in transfer-of-function studies, it may be useful to consider some of the methodological issues raised by the existing research and in so doing highlight issues worthy of further empirical attention. Several important issues can be identified, including the role of prior equivalence testing, the role of instructions, experimental designs, and whether immediate transfer was demonstrated. We shall now address each of these in turn.

The Role of Prior Equivalence Testing

Further investigation of the exact role played by prior equivalence testing in transfer-of-function research is required for several reasons. First, previous studies have shown that discriminative (Barnes & Keenan, 1993; Rehfeldt & Hayes, 1998b), self-discriminative (Dymond & Barnes, 1998), consequential (S. C. Hayes, Kohlenberg, & Hayes, 1991), and ordering (Wulfert & Hayes, 1988) functions can transfer through equivalence relations *without* a prior MTS test for such relations. Such findings suggest that the formal demonstration of derived relations was not necessary for stimulus functions to transfer. Occasionally, however, researchers have found it necessary to expose subjects to either symmetry (Hayes et al., 1991) or partial equivalence tests (Wulfert & Hayes, 1988) to facilitate the derived transfer performance. Thus, the specific functions served by testing for equivalence prior to transfer remain important empirical issues.

Second, it has been argued that the transfer of functions through equivalence relations following tests for equivalence is not reflective of genuine transfer of function, because the B and C stimuli are directly paired in equivalence tests, and functions can transfer through a second-order respondent-type process[1] (see Barnes & Keenan, 1993; Rehfeldt & Hayes, 1998a). When a transfer of functions occurs between two stimuli that have been paired in a prior equivalence test, it is uncertain whether the transfer has occurred via a derived equivalence relation. That is, the transfer may have occurred based on the compounding of the B and C stimuli during equivalence testing, and therefore would not have occurred had this test been omitted. In this way, the observed transfer effect is not a genuine instance of *derived* transfer of functions, because it emerged via a direct associative process (i.e., compounding) rather than through the derivation of stimulus relations (see Wulfert, Dougher, & Greenway, 1991). Researchers should note that alternative explanations are likely when the transferring stimuli were previously paired in an equivalence testing context.

Finally, the observation that mere exposure to a series of interrelated conditional discriminations, without testing for equivalence relations, can result in derived transfer clearly extends the analysis and importance of the transfer-of-function effect. In the everyday functioning of verbal behavior, the derivation of stimulus relations and the transfer of functions through these relations likely follows a different se-

[1] We are grateful to Dermot Barnes-Holmes for a discussion of the role of associative processes in the transfer of functions.

quence to that employed in research studies. Further investigation of the role of prior equivalence testing would permit the identification of possible facilitative factors for transfer, such as the minimum amount of conditional discrimination training required, the role of nodal distance in transfer, and the effectiveness of other, non-MTS (i.e., respondent-type) procedures in generating derived transfer. Because it appears that the transfer of functions and the emergence of equivalence relations tend to overlap, yet can also occur independently under some conditions (McIlvane & Dube, 1990), an identification of the conditions under which observations of both phenomena are likely or unlikely remains an important empirical goal.

The Role of Instructions

Despite the importance placed on possible instructional effects in human operant research, only a few studies have systematically examined the effects of instructions on derived transfer (Dymond & Barnes, 1994, 1998; Green et al., 1991; Sigurdardottir, Green, & Saunders, 1990). In general, three main types of instructional variables can be identified in transfer studies. The first type of instructional variable involves instructions that include relational terms such as "goes with" in the equivalence training and testing phases of transfer studies (e.g., Fields et al., 1996; Gatch & Osborne, 1989; Wulfert & Hayes, 1988). It has been argued that such relational terms, combined with the MTS format itself, may function as powerful contextual cues for equivalence responding in verbally sophisticated subjects (Barnes & Holmes, 1991; S. C. Hayes & Hayes, 1989), thus rendering any subsequent derived transfer performance ambiguous. Although a systematic study of instructional variables on equivalence class formation has yet to be undertaken, researchers should first consider the necessity or extent of the instructions provided to subjects prior to equivalence training and testing and the implications this may have for interpreting subsequent derived transfer performance.

The second type of instructional variable involves providing subjects with instructions that relate the equivalence and transfer phases of the study to each other. For instance, Wulfert and Hayes (1988, p. 128) and Greenway et al. (1996, p. 135) instructed subjects that "all the tasks are interrelated," whereas Dougher et al. (1994, p. 334) instructed subjects that "things that you learn in this part of the study [equivalence] may be important later on." Many studies provide separate instructions for different experimental phases but make tacit mention of the interrelationship between training and testing phases (e.g., giving the instruction, "continue to respond in a way that you consider correct," or "try your best," prior to transfer-test exposure). It seems reasonable to assume that such instructions might cue subjects that accurate responses from previous training phases might also be accurate upon the onset of testing phases. Subjects may thus persist with a particular response pattern in the absence of any direct feedback. Such instruction might either facilitate or inhibit derived transfer, yet no evidence exists to support one or the other of these conclusions. Future research should address the possible facilitative role played by these instructions in transfer studies by eliminating where possible all instructions that relate phases of the study together, by reducing the frequency of reinforcement during baseline training, and by interspersing reinforced baseline trials between nonreinforced probe trials during the transfer test (e.g., Barnes & Keenan, 1993; Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Dymond & Barnes, 1997b).

The final type of instructional variable concerns instructions that describe the contingencies of the operant response under study (e.g., Barnes & Keenan, 1993; Dymond & Barnes, 1994, 1998; Fields et al., 1996; Green et al., 1991; S. C. Hayes et al., 1991; Rehfeldt & Hayes, 1998b). Given the number of different stimulus functions that have been studied in recent years, it is perhaps not surprising to learn that researchers have found it expedient to instruct subjects regarding the particular response to be trained during transfer-of-function training. For instance, Dymond and Barnes (1994) employed two complex schedule combinations to generate two distinct patterns of responding during transfer-of-function training and testing. To initiate contact with the particular schedules, one of which was randomly generated on each trial, Dymond and Barnes instructed subjects to "either keep pressing the space-bar [a recycling conjunctive fixed-time 5-s fixed-ratio 1 schedule], or not press at all [a recycling conjunctive differential-reinforcement-of-other-behavior fixed-time 5-s schedule]. . . . There is no way you can get all the space-bar tasks correct, but the best strategy is to keep pressing on some tasks, and on other tasks not to press at all" (1994, p. 256). Although a further study determined that such "detailed" instructions were not necessary, either to initiate contact with the schedules or to facilitate derived transfer (Dymond & Barnes, 1998), the precise role played by these instructions remains unclear.

Future researchers might consider the role of instructions, both in training the desired transfer of function and in making any speculative leaps concerning the implications of derived transfer performance for an understanding of verbal behavior. This prescription is particularly important given historical emphases on the instructional effects demonstrated in seminal studies on human sensitivity to changing contingencies (see S. C. Hayes, 1989, 1994, p. 13; S. C. Hayes & Hayes, 1992; Madden, Chase, & Joyce, 1998). The concern that derived performances may, in fact, be instructed is also important because organisms that presumably would not understand instructions have failed to show derived relations (cf. Schusterman & Kastak, 1993). A suggested means of avoiding potential interpretative difficulties in the study of derived transfer would be to "design instructions with parsimony as a goal" (Pilgrim, 1998, p. 33) or, if possible, not to use them at all.

Experimental Designs and Transfer-Control Procedures

Transfer-of-function studies employ a number of different experimental designs, but the majority of studies adopt the following three-phase sequence of training and testing (e.g., Barnes & Keenan, 1993; Dymond & Barnes, 1994, 1998; Wulfert & Hayes, 1988). In the first phase, a minimum of two three-member equivalence relations are trained and tested (i.e., train A-B, A-C; test B-C). In the second phase, a particular function is trained for one stimulus (i.e., B1 = clap) and another function is trained for a second stimulus (i.e., B2 = wave). Finally, in the third phase the C stimuli are tested for a transfer of functions from the trained B stimuli through equivalence relations (i.e., C1 = clap?/C2 = wave?).

Exceptions to the three-phase sequence of training and testing may involve a reversal in the order of presentation of Phases 1 and 2 (e.g., S. C. Hayes et al., 1991; Rehfeldt & Hayes, 1998b; Roche & Barnes, 1997), with evidence suggesting that transfer of functions may be facilitated if the specific stimulus functions are trained before MTS training is conducted (S. C. Hayes et al., 1991). Similarly, researchers have found it expedient to test in Phase 3 for transfer to *all* remaining stimuli, not just the C stimuli (e.g., Dougher et al., 1994; Green et al., 1991; Rehfeldt & Hayes, 1998b). Recently Smeets, Barnes, and Roche (1997; see also Wasserman & DeVolder, 1993) employed a novel experimental design to demonstrate derived transfer of function without symmetry or equivalence. These researchers trained 4- and 5-year-old children to emit specific responses to pairs of in-

TABLE 1

Task sequences and examples of transfer-control procedures for transfer-of-function research

Equivalence control	Nonequivalence control	Transfer baseline
Train (and test): A-B/A-X Train: B function Test: C function (e.g., Barnes et al., 1995; Dymond & Barnes, 1994; Hayes et al., 1991)	Train: B function Test: C function (e.g., Dougher et al., 1994; Dymond & Barnes, 1994)	Test: C function Train (and test): A-B/A-X Train: B function Retest: C function (no published example)

dividual stimuli (A1-R1, B1-R1, A2-R2, B2-R2) in one setting (original training) and to emit other responses to one member of each pair (A1-R3, A2-R4) in another setting (reassignment training). Subjects were then tested across a number of phases for the emergence of derived stimulus–response relations (B1-R3, B2-R4), stimulus–stimulus relations (A1-B1, A2-B2, B1-A1, B2-A2), response–stimulus relations (R3-B1, R4-B2), and response–response relations (R1-R3, R2-R4). Modifications to the design of transfer-of-function studies such as those employed by Smeets et al. will inevitably contribute towards an understanding of the role played by equivalence testing in generating the derived performance.

Two related experimental design issues concern the presentation of trials from the above three phases and the use of transfer-control procedures. Regarding the first issue, transfer-test trials are usually presented either in discrete blocks (massed) or in mixed blocks including all trial types (i.e., baseline and probe). Research comparing the two procedures is scarce, but the limited evidence available does suggest a possible facilitative effect of mixed trial blocks on derived transfer. For example, after repeated training and testing with the massed arrangement, Barnes and Keenan (1993) exposed subjects to interspersed tasks and found that this facilitated derived transfer (cf. de Rose et al., 1988), whereas Dymond and Barnes (1997b) employed interspersed tasks from the outset and showed reliable transfer in 2 of 3 subjects. Interspersing transfer-test trials with other trial types or alternating blocks of transfer-test trials with blocks of other trial types also provides a means of assessing the stability of the prerequisite trained relations during crucial test phases. From the perspective of the subject, the successive presentation of interspersed tasks may facilitate the derivation of relations between the various trial types, which is also a common objective in instructions that specify the interrelationship between different tasks. Further empirical and conceptual analyses of the facilitative effects of interspersed trial types in derived transfer research are clearly needed.

The second experimental issue, transfer-control procedures, can identify sources of competing stimulus control in transfer studies. Surprisingly, only a limited number of studies have employed transfer-control procedures (Barnes, Browne, Smeets, & Roche, 1995; Dougher et al., 1994; Dymond & Barnes, 1994; S. C. Hayes et al., 1991, Experiment 4). Table 1 shows examples of at least three possible types of transfer-control procedures that can be employed in transfer-of-function studies. Two of the control procedures, equivalence and nonequivalence control, are designed to examine the extent to which MTS equivalence training and testing facilitate, and are necessary for, derived transfer. To illustrate, in their study on the transfer of self-discrimination response functions through equivalence relations, Dymond and Barnes (1994) employed two groups of 4 subjects, experimental and control. Subjects in the experimental group were first trained in six MTS tasks (A1-B1, A1-C1, A2-B2, A2-C2, A3-B3, A3-C3) and were then tested for the formation of three equivalence relations (A1-B1-C1, A2-B2-C2, A3-B3-C3). Following successful equivalence performances, two self-discrimination responses were trained; if the subject had not pressed the space bar, choosing one stimulus (B1) was reinforced, and if they did emit one or more space-bar presses, choosing another stimulus (B2) was reinforced. No new function was trained for B3. Finally, subjects were tested for a transfer of these self-discrimination response functions through derived equivalence relations (i.e., no response, choose C1; one or more responses, choose C2). Two subjects in the control group were not exposed to any form of MTS training and testing (nonequivalence control), and the remaining 2 subjects were exposed to MTS training and testing that incorporated stimuli not used during the transfer test (equivalence control: C1 and C2 were replaced with X1 and X2 during training, but C1 and C2 were used for the transfer tests). All 4 experimental subjects demonstrated the predicted formation of three equivalence relations and the transfer of self-discrimination response functions, whereas none of the control subjects did so. The control procedures employed in this study allowed the researchers to determine (a) that transfer of function was likely to occur only if subjects had received equivalence training or testing and (b) that the equivalence relations were the necessary relations required to show derived transfer.

The third type of control procedure, transfer baseline, involves presenting the to-be-tested C stimuli prior to any training and testing in order to establish a baseline from which to compare any resulting derived effects.[2] In other words, if the C stimuli do not evoke the behavioral function prior to training but do so reliably following the training procedures, we can be reasonably sure that the derived performance is due to the training and testing procedures of the study and not to some other undefined variable. To our knowledge, no published transfer-of-function study has employed such a control procedure. Future researchers might consider incorporating control procedures such as those outlined above in transfer studies.

Immediate Transfer?

Immediate transfer is defined as reaching a predetermined mastery criterion on the first exposure to a block of transfer-test trials. Occasionally, the predicted performance does not emerge on the first exposure and may require repeated exposures to the training and transfer-testing phases (e.g., Barnes & Keenan, 1993; S. C. Hayes et al., 1991). Demonstrations of immediate transfer are important for a number of reasons. First, immediate transfer on unreinforced transfer-test trials indicates that the predicted performances were largely derived from the trained relations and were not produced by adventitious feedback from the repeated training and testing often used in transfer of function studies (cf. Barnes & Keenan, 1993; S. C. Hayes et al., 1991, Experiment 4). A subject repeatedly exposed to the transfer-test phase until the predicted performance "emerges" is likely to obtain indirect feedback about his or her performance (i.e., "I keep getting the same problems; I must be doing something wrong"). This inadvertent feedback, combined with the limitations of two-choice procedures (Carrigan & Sidman, 1992) that have often been presented on transfer-test trials, casts doubt on whether any subsequent

[2] We are grateful to Lanny Fields for suggesting this procedure.

transfer performance can be considered to be truly derived. Second, employing a predetermined stability criterion during transfer testing allows the identification of stable but unpredicted performances (Barnes & Keenan, 1993, p. 63; Dymond & Barnes, 1994). A stability criterion, such as selection of the same *but not necessarily predicted* stimulus on at least 9 of 10 transfer-test trials, allows greater experimental control because testing will end given any stable performance, not just the predicted one. The inadvertent feedback effect may, of course, still occur before the stability criterion is achieved. However, if stable, predicted performances do emerge, this indicates that responding was largely derived from the trained relations, and was not produced by repeated transfer training and testing exposures. Finally, performances that fail to meet the stability criterion, whether predicted or unpredicted, may indicate either that the necessary stimulus relations were not formed, in which case subjects are usually returned to an earlier training phase, or that testing contexts inhibited derived transfer. Given that transfer-of-function studies typically employ different contexts for the training and testing of derived relations (usually MTS) and transfer (non-MTS), the identification of functional relations to explain why some subjects fail to demonstrate transfer is an important research topic that warrants further empirical investigation (see Greenway et al., 1996).

THE TRANSFORMATION OF STIMULUS FUNCTIONS AND RELATIONAL FRAME THEORY

"Transfer" Versus "Transformation" and the Challenge of Multiple Stimulus Relations

Thus far, we have used the specific term *transfer* to describe patterns of responding indicative of a transfer of functions through symmetry and equivalence relations. The relational frame theory of complex human behavior proposes the term *transformation* of stimulus functions as a generic substitute for *transfer* specifically and for derived relational responding more generally (e.g., equivalence performances). According to relational frame theory, the transformation of stimulus functions is a defining feature of derived relational responding (L. J. Hayes, 1992; S. C. Hayes et al., 1996). It is important to understand that relational frame theory distinguishes between the general concept of transformation of function and particular kinds of transformations, such as mutual entailment and combinatorial entailment. *Mutual entailment* is a generic term for relations that have inherent bidirectionality (e.g., if A is bigger than B, then B is smaller than A), and *combinatorial entailment* describes a combination of relational responses (e.g., if trained relations exist between X and Y and between Y and Z, these relations will, in a given context, combine to entail relations between X and Z and between Z and X). If one stimulus in a mutual or combinatorially entailed relation is given a direct psychological function, then the remaining stimuli may acquire this psychological function, transformed in accordance with the underlying derived relation. "For example, if 'lemon' is in an equivalence class with actual lemons in a context that selects taste as the relevant function, talking of lemons can be associated with salivation or puckering" (S. C. Hayes et al., 1998, p. 289).

In essence, all derived relational responding involves a transformation of functions (cf. L. J. Hayes, 1992). Relational frame theory contends that because functions may transform in accordance with a large variety of patterns, it is scientifically useful to discriminate these patterns from each other in a relatively consistent manner. These various patterns, which are specific instances of the general transformation of stimulus functions, are normally categorized as instances of the mutually and combinatorially entailed relations of coordination (i.e., sameness), opposition, comparison (e.g., more than or less than), temporal order (e.g., before or after), and so on (see S. C. Hayes & Hayes, 1989). In effect, the observed pattern of transformation of functions defines the entailed relations, and thus the entailed relations (e.g., symmetry and equivalence) do not exist as a behavioral event until a specific transformation of functions has occurred.

Evidence for this approach to derived relational responding is accumulating (e.g., Barnes-Holmes, Hayes, Dymond, & O'Hora, in press; Dymond & Barnes, 1995, 1996; S. C. Hayes & Barnes, 1997; S. C. Hayes, Barnes-Holmes, & Roche, in press; Roche & Barnes, 1997; Roche, Barnes-Holmes, Smeets, Barnes-Holmes, & McGeady, 2000; Steele & Hayes, 1991). In a recent study (Dymond & Barnes, 1995), 4 experimental subjects were pretrained in accordance with relations of sameness, more than, and less than. Responding in accordance with sameness was trained by asking subjects to pick a short-line comparison given a short-line sample in the presence of the SAME contextual cue. Responding in accordance with more than and less than relations was trained using comparisons that were either more than or less than the sample, respectively, along some physical dimension. For example, subjects were trained to pick a two-star comparison in the presence of a three-star sample given the LESS THAN cue and to pick a six-star comparison in the presence of the three-star sample given the MORE THAN cue. After the subjects had been successfully pretrained, they were trained in six arbitrary relations using the three contextual cues. The four critical relations were [SAME] A1-B1, [SAME] A1-C1, [LESS THAN] A1-B2, and [MORE THAN] A1-C2, where the first terms represent the contextual cues, the first alphanumeric symbol represents the sample stimulus, and the second alphanumeric symbol represents the reinforced or tested-for comparison choice. Subjects were then tested for seven derived relations, the following three relations being the most important: [SAME] B1-C1, MORE THAN/B1-C2, LESS THAN/B1-B2 (see Figure 2).

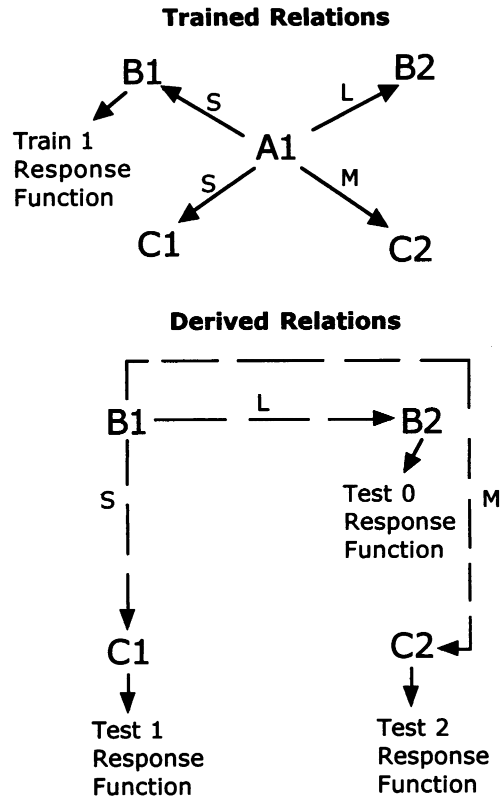

Figure 2. Basic relational network adapted from Dymond and Barnes (1995) showing the four important trained relations (upper panel) and three tested relations (lower panel). Letters S, M, and L indicate the arbitrarily applicable relations of sameness, more than, and less than. The diagram also shows that a one-response function was trained using the B1 stimulus, and tests examined the transformation of the trained self-discrimination response function in accordance with the relations of sameness (C1, one response), more than (C2, two responses), and less than (B2, no response). See text for details.

To study derived self-discrimination response functions in accordance with sameness, more than, and less than relations, three response functions were required. Subjects were trained using three reinforcement schedules to produce three performances (i.e., no response, one response only, and two responses only) and to choose a particular stimulus after each of these performances. It was predicted that if the derived sameness, more than, and less than relations had been established (i.e., B1 is the same as C1, C2 is more than B1, and B2 is less than B1), and choosing Stimulus B1 had been reinforced after making one response, a subject might without further training, choose (a) C1 following one response (i.e., C1 acquires the *same* function as B1), (b) C2 following two responses (i.e., C2 acquires a response function that is *more than* the B1 function), and (c) B2 following no response (i.e., B2 acquires a response function that is *less than* the B1 function; see Figure 1). All 4 pretrained subjects demonstrated the predicted transformation of self-discrimination response functions (i.e., no response, choose B2; respond once, choose C1; respond twice, choose C2).

The term *transformation* of functions was used to describe this effect instead of *transfer*, because the explicitly trained one-response function of B1 did not transfer to B2 and C2 (i.e., B2 and C2 did not acquire one-response functions). Rather, the one-response function of B1 *transformed* the functions of B2 and C2 in accordance with more than and less than relations. In effect, the three distinct responses that emerged on the self-discrimination tests defined the multiple stimulus relations of sameness, more than, and less than. For relational frame theory, explanations of findings such as these necessitate the adoption of the term *transformation* because the multiple response patterns observed defined three distinct combinatorially entailed relations (see Dymond & Barnes, 1995, pp. 182–183, for further discussion of alternative interpretations).

The Transformation of Stimulus Functions as Generalized Operant Behavior

It is important to understand that by appealing to *transformation* as a generic term, no kind of mediational process need be inferred (Barnes-Holmes & Barnes-Holmes, 2000; cf. Sidman, 1994, pp. 556–557). As emphasized before, the derived outcomes manifest on tests for a transformation of functions define the entailed relations. In this sense transformation refers both to the history necessary to produce a derived performance (i.e., a history of relating arbitrary stimuli in the presence of contextual cues) and to a description of the particular experimental outcome. Accordingly, relational frame theory makes empirical predictions about the types of reinforcement histories necessary to demonstrate derived behavior. Approaching the study of derived stimulus relations and the transformation of functions in this way opens up the study of derived performances to an investigation of the operant nature of relational activity in general (e.g., S. C. Hayes et al., 1996; Healy, Barnes, & Smeets, 1998). For relational frame theory, the aim is to provide an account of derived relational responding as generalized operant behavior (see Barnes-Holmes & Barnes-Holmes, 2000). Several strands of research can be identified as supporting this dimension of relational frame theory. Derived relational responding shows many of the properties of operant behavior, such as development over time (e.g., Lipkens, Hayes, & Hayes, 1993), flexibility (e.g., Roche et al., 1997; Wilson & Hayes, 1996), antecedent stimulus control (e.g., Dymond & Barnes, 1995, 1996; Roche & Barnes, 1997; Steele & Hayes, 1991), and consequential control (e.g., Healy et al., 1998). Although further empirical work must be conducted before the relative merits of approaching relational responding as operant behavior can be fully assessed, the evidence so far suggests that such an enterprise is likely to further inform contemporary behavior-analytic accounts of complex behavior.

FUTURE DIRECTIONS FOR TRANSFORMATION RESEARCH

Clearly, tremendous advantages are afforded verbal humans by the transformation of functions, because a wide range of seemingly generative behavior is made possible in the absence of a direct conditioning history. An appropriate subject population with whom to examine these advantages might be young children who are in the process of acquiring a range of derived behaviors. For this reason, a potentially useful area of future research is the longitudinal investigation of the development of derived transformation repertoires in young children. At what point developmentally does the ability to demonstrate the derived transformation of functions through equivalence typically occur, and what is the nature of the relationship between transformation of function and other verbal behavioral processes (e.g., rule following)? The earliest age at which a transformation of discriminative functions was reported is 3 years old (Barnes et al., 1995), whereas derived symmetrical relations have been observed in a 16-month-old infant (Lipkens et al., 1993). How much earlier might children prove to be capable of demonstrating derived transformation? How much experience with function transformation, if any, is necessary before stimulus equivalence and other derived relations can be demonstrated? Both of these are important empirical questions.

Future research might also focus on the stability of derived transformation effects over time. The existing body of evidence for the untrained acquisition of stimulus functions is noteworthy for the reasons discussed thus far, but understanding the longevity of derived stimulus control is also critical. For how long might a stimulus be shown to exert derived transformation of control in the absence of contact with the original training stimulus? Such a finding would have implications for the analysis of clinically significant anxiety, which

> appears to refer to avoidance responses whose initiating conditions are direct but very remote and whose perpetuating conditions are mostly derived. The life of the clinically anxious person may be influenced by iterations and reiterations of public and private events with reactive properties traceable to initiating conditions only through an almost fractal pathway involving the processes of stimulus generalization, derived relational responding, and transformation of stimulus functions. (Friman et al., 1998, p. 143)

The maintenance over time of many forms of behavior, in the absence of a period of retraining, is highly desirable. For example, children are likely to learn that the spoken word "fire!" is symbolically related to an actual fire. The children may have been directly taught that covering their mouths and exiting immediately are appropriate behaviors when they hear another individual yell "fire!" We hope that this discriminative control would transform the functions of an actual fire, occasioning the same behaviors should the children come into contact with a real fire. Moreover, we also hope that these transformation effects would endure for some time without having to retrain the original behaviors in the presence of the spoken word "fire!" Clearly, the development of new procedures that mirror everyday instances of derived relational control, such as stability over time, remains an important empirical objective.

Conclusion

Decades ago, researchers in the experimental analysis of behavior lacked the tools needed to explain novel behaviors emitted in the absence of a direct history of reinforcement. In fact, at one time such observations may have provided fuel for the criticisms (and subsequent misrepresentations) of radical behaviorism by other psychologists; such observations seemed to refute the role of an organism's past learning history in accounting for behavior in the present. Today, however, due to the recent research efforts from a number of laboratories, such complex behavior can be approached and understood from a behavior-analytic perspective. We hope that this review will serve as a useful catalogue of existing studies on the transformation of stimulus functions, and that it will incite continued research in an attempt to understand derived relational responding and complex human behavior.

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