

## Symmetrical Reasoning and Representation: A Human Cognitive Specialization?

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Poster Presented at the Conference on Human Cognitive Specializations: Developmental and Comparative Perspectives. Lafayette/New Iberia, Louisiana, October 15-18, 1998.

Abstract:

Symmetrical reasoning and representation occur ubiquitously in humans. For example, tests using “if-then” relations show that humans generally reverse these relations. This phenomena is termed “emergent symmetry” because, after learning experiences with if-then relations, humans generally show performance on the symmetrical or reverse relations with no additional training. We outline four potential hypotheses for the comparative psychological study of emergent symmetry. Data are summarized regarding some prior tests of emergent symmetry in nonhuman animals, and we report on the results of new tests, with rats, in the spatial domain. It is suggested that the most likely hypothesis regarding emergent symmetry, and potentially other forms of symmetrical reasoning and representation, is that this is a human cognitive specialization. Some recent neuropsychological data with monkeys are surveyed, regarding symmetries in motor action-perception, and this is suggested as a potential phylogenetic source of at least some human symmetry abilities.

## **Symmetrical Reasoning and Representation**

In this poster, we consider aspects of the comparative psychology of symmetrical reasoning and representation. Symmetrical reasoning and representation occur ubiquitously in humans and various proposals have placed symmetrical reasoning and representation at the core of human cognition. Table 1 summarizes some human symmetry phenomena. Piaget (1972) included reversibility or symmetry as a defining property of operational thought in children. For Piaget, it was the reversible use of asymmetrical relationships that marked the cognitive transition to concrete operations. Singley and Anderson (1989) suggested that the symmetry-asymmetry distinction is critical to the difference between declarative and procedural memory. Procedural knowledge structures, such as those modeled by condition-action “production” rules “imply a directional asymmetry” (p. 200), whereas declarative knowledge structures imply a directional symmetry. Intuitively, this seems to correspond well to reasoning about time. Procedural knowledge structures (such as those modeled by production rules) enable reasoning forward in time, while declarative knowledge structures enable reasoning either forward or *backwards* in time. Relational properties of symmetry also seem vital in certain types of abstract categorization. The formation of equivalence classes or partitions (e.g., see Sidman & Tailby, 1982) requires abilities with a property of symmetry (along with transitivity and reflexivity or identity). This form of categorization groups arbitrary stimuli together, and thus is non-perceptual or abstract. The term “emergent symmetry” is used in this area and refers to a property of symmetry which emerges automatically (as an untrained result) based on initial, asymmetrical

experience. The remainder of this poster is concerned primarily with the comparative psychology of emergent symmetry.

Tests for emergent symmetry (Sidman & Tailby, 1982) give subjects experience with “if-then” conditional relations in a match-to-sample procedure. The tests then assess for the subjects’ competence with the symmetrical or reverse relations. Humans generally show immediate (“emergent”) performance on the symmetrical or reverse relations. An example of this procedure is given in Table 2. Subjects are first trained on “if cup then blue” (select the blue card from amongst blue and green alternatives when presented with the cup), and “if ball then green” (see Table 2A). They are then tested on the reverse of these conditional relations: “if blue then cup” and “if green then ball” (see Table 2B). Subjects showing immediate and consistently high levels of performance on the reverse relations have shown “emergent symmetry.”

### **Comparative Psychology: Emergent Symmetry**

Hypotheses. Table 3 presents four potential comparative psychological hypotheses regarding emergent symmetry. These are labeled S0, S1, S2, and S3. At the outset, we might expect to find evidence for emergent symmetry in the psychology of various nonhuman animal species – Hypothesis S0 covers this possibility. Hypothesis S1 suggests that emergent symmetry may not appear in initial tests with other animals, but given extended experiences with symmetrical situations, these other animals may come to show this cognitive skill. This hypothesis may have some potential as a phylogenetic hypothesis – since the ontogenetic paths to human emergent symmetry may involve experiential factors, we cannot yet rule out the possibility that instances of emergent

symmetry in nonhumans that involve extensive training are homologous to emergent symmetry in humans. Another potential is that nonhuman animals may display emergent symmetry in domains different from humans (Hypothesis S2). For example, humans exhibit object-oriented skills, while other animals may generally exhibit their premier cognitive skills in social or spatial domains (e.g., Jolly, 1966; also see p. 191, Tolman, 1932). Hypothesis S2 also forms a phylogenetic hypothesis: It may lead us towards domain specific avenues from which human emergent symmetry evolved. By assessing other animals for domain specific forms of emergent symmetry we may uncover shared cognitive skills that underlie the human competence of emergent symmetry. A final hypothesis (S3) is that emergent symmetry is a human cognitive specialization. While this hypothesis may be hard to verify, we should keep it open as a possibility. We will be assisted in our evaluation of Hypothesis S3 by tracing the ontogenetic path of emergent symmetry in humans, and considering evidence for underpinning mechanisms in other animals.

Prior data. The data regarding nonhuman animal testing for emergent symmetry has been evaluated in Prince (in progress). The general finding is that nonhuman animals (baboons, chimpanzees, monkeys, parakeets, pigeons, rats, and sea lions have been tested) display emergent symmetry in some tests while they do not exhibit it in others. Early studies tested Hypothesis S0 (e.g., Sidman, Rauzin, Lazar, Cunningham, & Carrigan, 1982), while more recent studies have evaluated Hypotheses S1 and S2. Schusterman and Kastak (1993) trained and tested a single sea lion subject and used a technique that provided the sea lion with training on multiple sets of symmetry exemplars. These authors found evidence for Hypothesis S1 with these methods – their subject

showed evidence for emergent symmetry. Bunsey and Eichenbaum (1996) tested Hypotheses S1 and S2. They tested rats in the olfactory domain using training on multiple symmetry exemplars and found some transfer of learning on symmetry relations. Manabe, Kawashima, and Staddon (1995) tested parakeets in a Hypothesis S2 paradigm – they used vocal stimuli with the birds. These authors found some suggestion for emergent symmetry, but a small sampling size (five experimental outcomes in which three birds were studied) may restrict strong interpretations of their results.

Spatial domain tests. We have recently conducted tests with rats in the spatial domain, for an evaluation of Hypothesis S2. Our hypothesis was that since rats display good cognitive skills in the spatial domain (Morris, 1981; O’Keefe & Nadel, 1978; Olton & Samuelson, 1976), and that since rats show abilities with relations regarding groups of locations (Dallal & Meck, 1990; Macuda & Roberts, 1995), they may show evidence for emergent symmetry in the spatial domain. Our method trained rats on relations between locations such as given in Table 4. We used a procedure consisting of a training phase followed by testing phase. In the training phase, forward relations between locations were trained. For example (see Table 4A), with four maze locations (four arms on a radial-maze; see Olton & Samuelson, 1976), and the NORTH and EAST locations baited with food, the rat would be started at the NORTH location and trained to run to the EAST location (“if-NORTH-then-EAST”). In training the other relation the WEST and SOUTH locations were baited, the rat was started WEST, and trained to run SOUTH (“if-WEST-then-SOUTH”). In the testing phase, these relations were reversed (see Table 4B). That is, individual rats were now tested on “if-EAST-then-NORTH” (with EAST and NORTH locations baited, and the rat started EAST), and “if-SOUTH-then-WEST.” Spatial

emergent symmetry would be displayed by the rats if they performed correctly on the testing trials immediately after experience with the training trials. Figure 1 shows a schematic of the radial-maze and the correct response running-paths followed by the rats in training (solid arrows) and testing (dashed arrows). In Experiments 2 and 3, aside from the differences in starting locations, there were no procedural differences from training to testing.

Three experiments were conducted, with a new group of 12 rats (Long-Evans Hooded rats) used in each separate experiment. Table 5 summarizes the apparatus, procedure, and results from these experiments. Experiment 3 comprised a control experiment. Since Experiments 1 and 2 were conducted on a radial-maze and showed no signs of transfer of learning from forward relations to backward relations, we constructed a new maze – having both proximal and distal cues – to evaluate if an enhanced maze would result in transfer of learning in rats. Figures 2 and 3 show the radial maze and enhanced mazes, respectively (color images of these mazes are available on the Internet at <http://www.cacs.usl.edu/~cgp>). Figure 4 provides some details of the average results in each experiment. We compared the mean number of training trials in each experiment to the mean number of testing trials. Using paired t-tests there were no statistically significant differences of mean number of trials to criteria in training compared to mean number of trials to criteria in testing. Figure 5 shows a plot of the number of training trials versus the number of testing trials across all three experiments (for the rats meeting the training criteria). Across all three experiments there was a statistically significant ( $p = 0.03$ ) linear correlation in this data (slope = 0.53). While within each experiment the results indicate no transfer of learning, this correlation result across all three experiments

suggests a slight benefit of the learning of the forward relations to the learning of the backward relations.

### **Emergent Symmetry as a Human Specialization**

The data from tests for emergent symmetry in nonhuman animals are variable. Hypothesis S0 (see Table 3) does not seem particularly likely given the data from prior experiments (see also Prince, in progress). Data from tests of Hypothesis S1 do show some interesting results (e.g., Schusterman & Kastak, 1993, 1998), but further empirical and theoretical work is needed to identify the relation of these trained nonhuman animal performances to human performances. Data from tests for Hypothesis S2, while in their infancy (e.g., Bunsey & Eichenbaum, 1996; Prince, in progress), do not show striking results.

Production-comprehension symmetry. It seems clear that we need to supplement these above investigations on nonhuman animals with the details of the origins of emergent symmetry in humans. In addition to keeping an open mind regarding hypotheses for emergent symmetry and other animals (Hypotheses S0, S1, and S2), we would be wise to entertain the hypothesis that emergent symmetry may be a human specialization (Hypothesis S3). Indeed, one reading of the data from nonhuman animals, to date, is that Hypothesis S3 is the most likely candidate. Horne and Lowe (1996) have proposed a theory related to Hypothesis S3. They have suggested that emergent symmetry arises in the conjoining of the language production and comprehension skills of human children: “This fusion of ... speaker and listener functions establishes a qualitatively new bidirectional relation in the child’s behavioral repertoire” (p. 200).

Neuropsychology of monkeys. Given this basic theorizing about the ontogeny of emergent symmetry in humans, one way of investigating Hypothesis S3 is to investigate the potential phylogenetic origins of this production-comprehension “fusion” in humans. Rizzolatti and Arbib (1988) have suggested that language production-comprehension fusion may have arisen in large part because of the contributions of two types of cognitive systems. Rizzolatti and others (e.g., di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) have found evidence for a motor action-perception “mirror” system in area F5 (the apparent Broca’s area homolog) of the macaque monkey (Macaca nemestrina) brain. This brain area in monkeys seems to represent action-perception abstractions of specific actions – such as grasping, manipulating, and tearing. In combination with a “capacity to notice that one has emitted a signal and associat[e] it with changes of the behavior of others” (p. 191, Rizzolatti & Arbib, 1998), Rizzolatti and Arbib have proposed that these systems provided a basis for the evolution of production-comprehension symmetry in language. This production-comprehension symmetry starts to resemble joint visual attention (e.g., Butterworth & Cochran, 1980), and it is interesting to note that some authors (Baron-Cohen, 1994; Gómez, 1994) have discussed the potential for bidirectionality and simultaneous bidirectionality in the context of joint visual attention.

## **Conclusions**

We have reviewed one type of data regarding symmetrical reasoning and representation in nonhuman animals and in human animals. While there are a variety of hypotheses we can consider regarding this ability – focused on emergent symmetry – in

other animals, the most tenable hypothesis appears to be that emergent symmetry is a human cognitive specialization. Aside from tests in which other animals have been extensively trained (e.g., Bunsey & Eichenbaum, 1996; Schusterman & Kastak, 1993), nonhuman animals generally do not perform well on these tests of emergent symmetry. Additionally, the relation of these training-based nonhuman animal performances (Hypothesis S1; see Table 3) has yet to be unequivocally related to human cognitive performances. Even when we test animals such as rats in their cognitive areas of (apparent) strength – spatial cognition – they do not show evidence for emergent symmetry (Hypothesis S2; see Table 3).

Promising areas for evaluating Hypothesis S3 (see Table 3) – that emergent symmetry is a human cognitive specialization – are in the ontogenetic and phylogenetic origins of symmetry abilities. Rizzolatti and Arbib (1988) have suggested that a known primate neuropsychological system (cells that abstractly represent both the perception and action of certain behaviors in monkeys) plus a system that dynamically relates emitted signals of self to the behavior of others may lay the phylogenetic basis for production-comprehension “fusion” in language. Other authors (Horne & Lowe, 1996) have suggested production-comprehension fusion as a basis for a symmetry cognitive specialization in humans.

## **Acknowledgements**

I thank my dissertation advisor, Daniel J. Povinelli, for his continued support of this research. I am also indebted to my other committee members – Anthony S. Maida, Claude Oech, and Subrata Dasgupta. A grant from Sigma Xi partially funded the rat studies.

Table 1. Symmetrical Reasoning and Representation in Humans

<b>Phenomena</b>	<b>Literature</b>
Emergent symmetry (match-to-sample tests)	Sidman & Tailby (1982); Horne & Lowe (1996)
Associative symmetry	Asch & Ebenholtz (1962)
Language Production-Comprehension (generally)	Harris, Yeeles, Chasin, & Oakley (1995)
Piagetian reversibility (e.g., larger-than/smaller-than)	Piaget (1972)
Representational: If <u>aRb</u> is represented, then <u>bRa</u> can also be represented	Fodor & Pylyshyn (1988)
Wason selection task?	Wason (1966)

Tables 2A and 2B. Examples of Relations Used in Training and Testing for Object-Oriented Emergent Symmetry

Table 2A

Examples of Relations Used in Forward Direction If-then Training

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if cup then blue

if ball then green

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Table 2B

Examples of Relations Used in Emergent Symmetry Testing

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if blue then cup

if green then ball

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Table 3. Comparative Psychological Hypotheses Regarding Emergent Symmetry

Hypothesis	Hypothesis Description
S0	Unrestricted emergent symmetry (similar to that of humans) appears in a number of nonhuman animal species
S1	Emergent symmetry in other animals occurs in other (e.g., non-object-oriented) domains
S2	Emergent symmetry in animals results from (e.g., human supplied) training or experiences
S3	Emergent symmetry is a human cognitive specialization (phylogenetic precursors may be found in closely related species)

Tables 4A and 4B. Examples of Relations Used in Training and Testing for Spatial Emergent Symmetry

Table 4A

Examples of Relations Used in Forward Direction If-then Spatial

Relation Training

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if food is first found NORTH then food can next be found EAST

if food is first found WEST then food can next be found SOUTH

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Table 4B

Examples of Relations Used in Spatial Emergent Symmetry Testing

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if food is first found EAST then food can next be found NORTH

if food is first found SOUTH then food can next be found WEST

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Table 5. Summary of Three Experiments Conducted

Experiment	Maze	Procedure	Results
1	Radial	Goal location baited	5/12 rats tested no symmetry
2	Radial	Both locations baited	12 rats tested no symmetry
3	Enhanced	Both locations baited	4/12 rats tested no symmetry

Figure 1. Schematic of Radial-Maze Showing Training and Testing Relations.

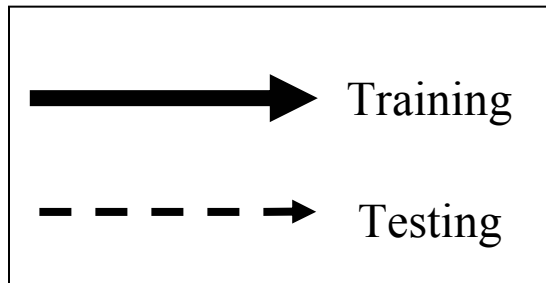
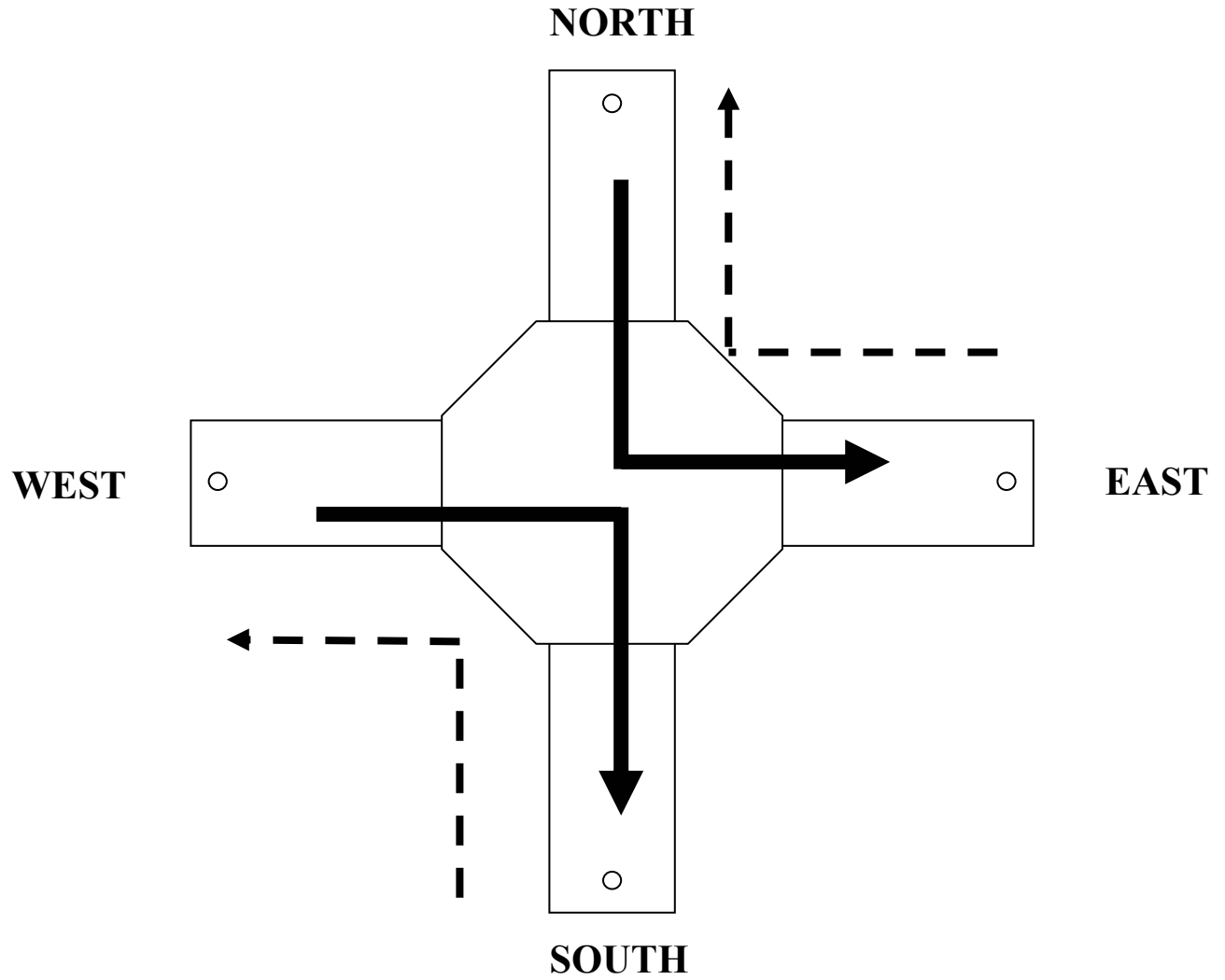


Figure 4. Summary of Results of the Three Experiments Conducted

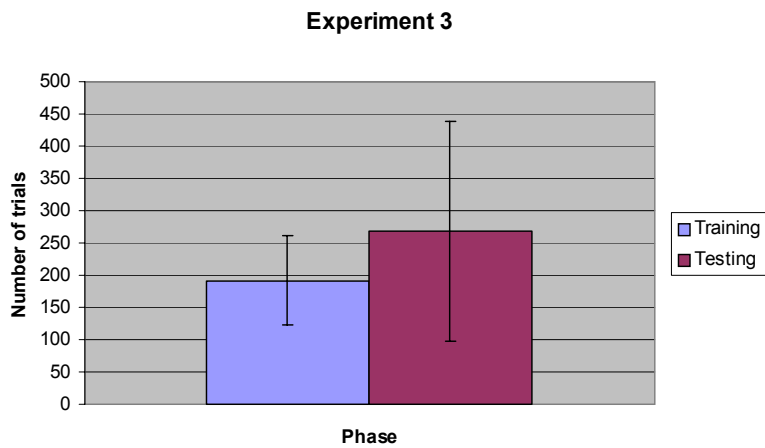
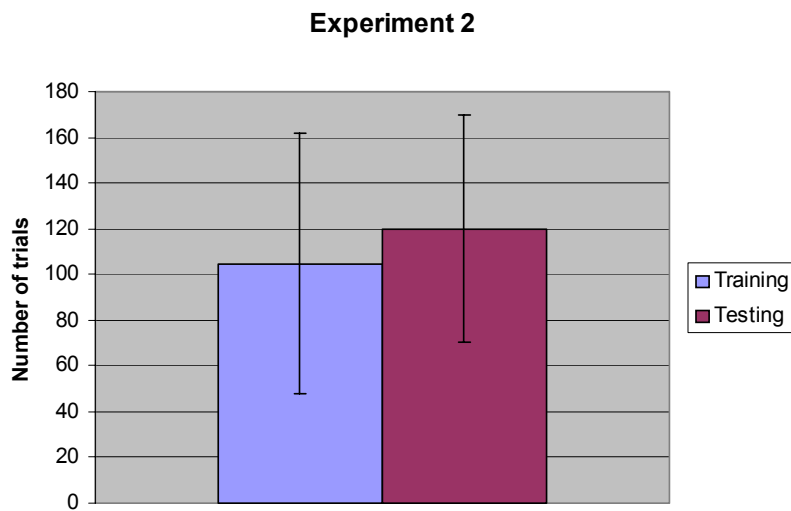
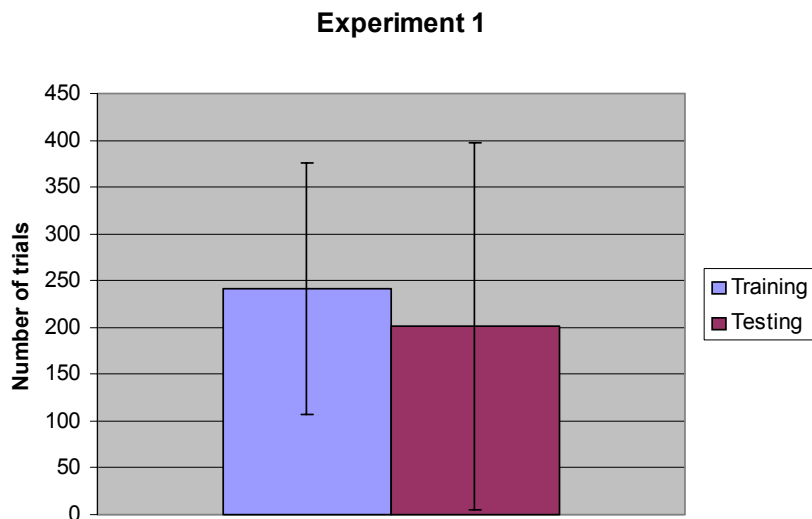
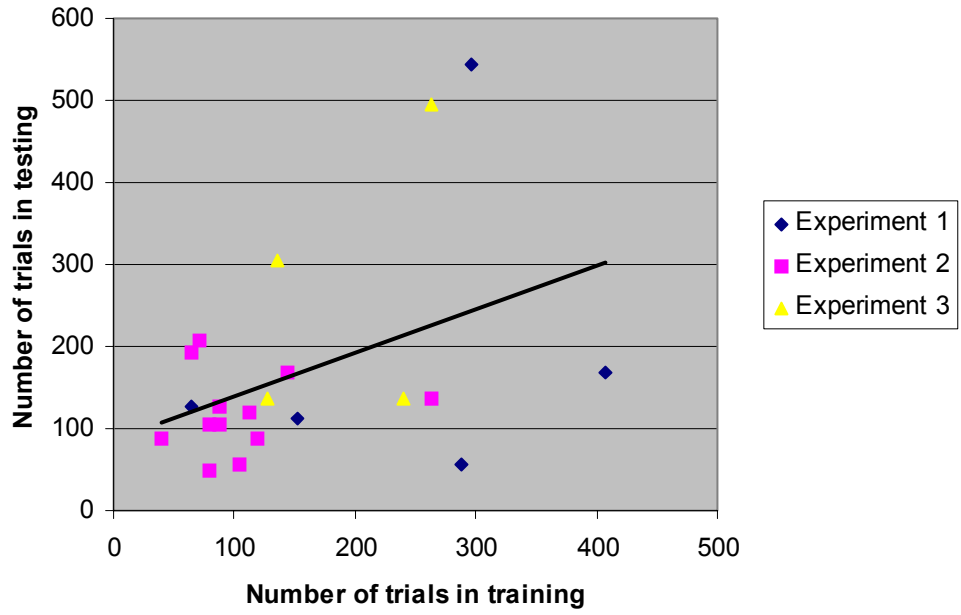


Figure 5. Results Across All Three Experiments



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