Engineering Discovery Learning: The Contingency Adduction of Some Precursors of Textual Responding in a Beginning Reading Program

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A learning situation in which the principal content of what is to be learned is not given but is independently discovered by the learner is often considered "discovery learning." Recently, learning scientists have been able to make explicit some of the conditions under which such independent discovery is likely to occur (Andronis, 1983; Epstein, 1996; Johnson & Layng, 1992). One form of "discovery" can often be observed when skills learned under one set of conditions are recruited under new conditions to serve a new or different function—a process of "contingency adduction" (Andronis, Layng, & Goldiamond, 1997). The research reported here investigated the application of contingency adduction in a discovery learning context to establish sound-to-letter correspondence as part of an online reading/decoding program, Headsprout Early Reading. Beginning readers acquired novel letters/sounds correspondence with minimal presentations and few errors—often requiring only one presentation. This research suggests that instructional sequences may be designed to provide effective discovery learning activities to teach some phonics skills.

> Hiero II requested that Archimedes find a method for determining whether a crown was pure gold or alloyed with silver. When he stepped into a bath he realized that a given weight of gold would displace less water than an equal weight of silver (which is less dense than gold); at this point he shouted, "EUREKA" (I have found it!). (Reported in Clark, 1999)

Since the time of Archimedes, scientists have observed that behaviors learned under one set of circumstances may alone, or combined with other behaviors, be recruited by a completely different set of circumstances into new stimulus-response classes, or to serve a new or different function (see for example Andronis, 1983; Schiller, 1957). In its most fundamental sense, discovery learning is based on these "Aha!" events. Many have considered these events essential to understanding novel performance, problem solving, and creativity (see for example Brownowski, 1978; Layng, 1991, 1995); yet, the precise conditions responsible for them have only recently been extensively investigated.

The actual moment of recruitment (of a repertoire) established under one set of conditions by an entirely different set of conditions, the "Aha!" moment, was given the name "contingency adduction" (Andronis, 1983; Andronis, Layng, & Goldiamond, 1997; Layng & Andronis, 1984). The word "recruitment" is used to distinguish contingency adduction from shaping by successive approximations. That is, the skills come "pre-shaped," and are selected or recruited by a different contingency than the contingencies responsible for the initial shaping.

Andronis (et al., 1997) reported two procedures (among others) that were effective in making the contingency adduction process explicit. One way to observe contingency adduction is to have the subject respond away from a previously learned stimulus, such that guidance by another stimulus can be recruited (selected) by a new contingent consequence, termed an oddity-from-sample procedure. Another procedure is to bring one behavior under the guidance of one stimulus and a different behavior under the guidance of another stimulus, combine the two separate stimuli into a single presentation, and from the responding occasioned by the combined guidance, select via a contingent consequence a new behavioral

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"blend." This is termed a combined stimulus procedure. The moment of selection under new contingent conditions, which differ from the original training conditions, marks the moment of adduction.[1]

Contingency adduction is an important facet of *generative instruction* (Johnson & Layng, 1992; Layng, Twyman, & Stikeleather, in press). Generative instruction is best described as a careful sequence of procedures that establish key component skills, provides practice of the skills to near fluency (automaticity), and then provides environments that increase the likelihood that the component skills will combine into more complex composite skills with little additional instruction. Often there is a mix of instruction and "engineered" discovery, using contingency adduction, which together may result in the rapid acquisition of complex skills and strategies.

In the case of efficient and effective phonics instruction the question is raised: Can contingency adduction be applied in a generative instruction sequence to engineer successful discovery learning by beginning readers? The research reported here investigated the application of contingency adduction tactics to rapidly establish sound-to-letter correspondence in the context of an online early reading program for beginning readers, Headsprout Early Reading (Part I). The experimental methodology was based upon a single subject design (Neuman & McCormick, 2002; Sidman, 1960) within a control analysis strategy (Goldiamond & Thompson, 1967, reprinted 2003) employed during formative evaluation that focused on experimental rather than statistical control of the relevant variables. Two methods were used to facilitate the adduction of new patterns from the constituents of old: an oddity-from-sample procedure and a combined stimulus procedure.

Method

Apparatus

A computer, a web browser with a Macromedia Flash plug-in, a mouse, and the Headsprout Early Reading online program comprised the apparatus for this investigation. Many computer configurations and platforms were used across learners. Minimum configuration requirements can be found at www.headsprout.com. The program, which resides on Headsprout servers, was presented while the learner was logged on to the Internet. All learner responses were continuously recorded and uploaded to the Headsprout servers.

Participants

Three learners (two girls and one boy, age 4 years 2 months, 4 years 7 months, and 4 years 11 months), who used the program in Headsprout's on-site user test lab where their performance could be carefully monitored, participated in a carefully controlled evaluation of the sequence. Prior to the sequence or any Headsprout instruction, participant reading abilities were assessed using the Woodcock-Johnson III Letter-Word Identification subtest and an in-house criterion-reference test of words made up of elements and sight words taught in the Headsprout program. Woodcock-Johnson scores for the participants indicate limited letter and sight word recognition performance. Each participant correctly read only 1 of the 50 words on the Headsprout word list test, further indicating little or no entry reading skills. Participant characteristics and entry scores may be found in the Table.

In addition, the data from over 32,000 children serving as participants (hereafter referred to as learners) were analyzed for this study. These data represent actual consumers of the online Headsprout Early Reading (Part I) program, and comprise paying customers using the program at home (53%), paying customers and pilot programs using the program in schools (46%), and beta or user test participants (1%). These learners came from a cross section of socioeconomic, gender, racial, and geographic

[1] A variety of other procedures investigated by both the Chicago and Harvard groups may be used to produce candidate repertoires for contingency adduction. These include terminating the incentives for current behavior such that other historically incented behaviors will reoccur and become candidates for adduction, pacing the delivery of contingent incentives or consequences such that unspecified behaviors are likely to occur and become candidates for adduction, and changing conditions such that behaviors that have in the past worked to solve a problem are no longer effective, resulting in increasingly less related behaviors occurring until a new repertoire is adduced based on novel combinations of past behaviors.

Table
Participant Characteristics for 3 On-Site Learners

Participant	Gender	Age[1] (y-m)	Woodcock-Johnson III Letter-Word Identification		Headsprout Wordlist (correct/total)[2]
			Raw Score	Grade Equivalent[3]	
TS	M	4-11	12	.5	1/50
OS	F	4-2	10	.1	1/50
SC	F	4-7	11	.3	1/50

[1] Participant age at onset of the Headsprout reading program.
[2] Pre-test on sight words and decodable words made up of phonetic elements taught in the program (including those used in the oddity and combined stimulus procedures), administered before beginning the reading program.
[3] Decimals represent the month of the school year, in this case the x month of Kindergarten.

demographics, of which being a non-reader or having minimal reading skills was a common characteristic. Learners were young children, the majority (68%) ranging in age from 4- to 6-years old (8% were below the age of 4 years, and 24% were slightly above the age of 6 years). The average age across all learners was 5.2 years (median 5.0 years). Of all participants, 10% were categorized as special needs learners and 4% were characterized as English language learners by either their parents[2] or school officials. Since the data were collected from the complete pool of users who had used or were currently using the program at the time of this analysis, learner were in different stages of program completion; accordingly, not all learners participated in all conditions.

General Procedures

All instruction was presented via the computer, with learners accessing an Internet-delivered instructional program [Headsprout Early Reading (Part I)]. For the 3 learners in the controlled evaluation study, a usability-testing specialist, in the Headsprout user test lab where participants would come to engage in the Headsprout online lessons, conducted all pre-instruction probes. Prior to each lesson, participant ability to perform the lesson objectives was assessed by presenting the phonetic element, word, or sentences to be taught on the computer screen and asking the learner to say or point to the target stimulus (depending upon the lesson's objectives). Within this format, selection probe data corresponding to the tested phonetic units were collected for these learners. No feedback on the accuracy of the response was given, and the occurrence/non-occurrence of correct responses was recorded. All learner sessions were monitored by the usability-testing specialist, and videotaped for later review.

Prior to each adduction opportunity, a set of phonetic elements (sound units represented visually by single or multiple letters, including consonants, vowels, blends, digraphs, dipthongs, etc.) were taught by a systematic progression of instructional routines (see Layng, Twyman, & Stikeleather, in press; Twyman, Layng, Stikeleather & Hobbins, 2004). These routines first established letter-sound correspondence by asking learners to:

1. click on a colorful graphic to present themselves with letter then sound pairings; and continue clicking to present themselves with sound then letter pairings;

2. click on a letter or letter set (hereafter referred to as phonetic elements) upon hearing the sound; then

3. select the phonetic element from an array

[2] Learners using the program at home received a special education designation only if their parents self-reported special needs by checking a box with the following statement: "Headsprout Reading Basics was not designed for special needs learners, however some parents have tried it and been pleased. It's very important that you let us know if your child is a special needs learner."

of other phonetic elements easily confused with the target element;

4. learn another phonetic element within the same instructional routines (1–3);

5. conditionally select taught phonetic elements placed together in a new array based upon the sound presented orally by the computer narrator;

6. pick the phonetic elements out of words (segmenting); and

7. complete timed-practice exercises to ensure segmenting fluency.[3]

Oddity-from-sample procedure. The objective of this task was to teach the participants to segment combined sounds into their constituent sounds without having been directly taught the separate constituent sounds. For example, a previously learned phonetic set (e.g. "cl") was displayed. As the narrator said, "Some sounds have other sounds inside them," the "cl" moved to the side of the screen and "c" was added to the display. The narrator then said, "Click on the sound that does not say /cl/." The auditory stimulus /cl/ was presented as the sample, and the learner could select either the displayed "cl" or "c." While this procedure might be more precisely described as a symbolic oddity from sample procedure where the oddity relation is potentiated by the accompanying auditory instruction, for ease of presentation we will simply refer to it as oddity-from-sample. If the learner clicked on "cl," the instruction was repeated. If the learner clicked on "c," the narrator simply said "/c/." Next "c" was presented alongside "cl" and "l." The narrator then said, "Click on /c/." If the learner clicked on "c," the narrator said, "Yes, /c/." This feedback event marked the point of adduction. If the learner clicked on another stimulus they were told, "That's not it," and the instruction was repeated. The same process was applied to adduce the "l" and all other oddity discriminations.

The set of sounds taught prior to presenting the oddity-from-sample procedure, and pronounced by the narrator as blends, were /an/, /cl/, /fr/, and /ip/. The sounds tested for contingency adduction were /n/, /c/, /l/, /f/, /r/, and /p/.

Combined stimulus procedure. The objective of this task was to blend individually learned sounds into a combined sound, without having been directly taught the blend. The set of sounds taught prior to presenting the combined stimulus procedure were /c/, /r/, /f/, /l/, /s/, /p/, /r/, /t/, /n/ (/n/ was previously adduced from /an/). The sounds tested for contingency adduction were /sn/, /cr/, /sl/, /fl/, /pl/, /pr/, /sp/, /tr/, /st/.

In this routine the narrator introduces the activity by saying, "I bet you can figure out new sounds all by yourself." Four sets of stimuli are presented on the display screen (for example, "pl," "ve," "ne," "sl") with the narrator's instruction, "Click on /sl/" (the target was pronounced as a blend /sl/, not as individual sounds /s/ /l/). If the learner clicks on "sl," the narrator says, "You're right /sl/." This contingent confirmation marks the point of adduction.

The learner is asked to do the task again with the stimuli rearranged to make sure the "sl" wasn't selected by chance. If the learner clicks on a different stimulus, the other stimuli are removed from the screen (leaving the error stimulus on screen) and the learner is told, "That's not /sl/." All stimuli reappear in a rearranged array, and the learner is asked once again to "Click on /sl/." If the learner does not click on "sl" on this second opportunity, a teaching sequence is presented that directly teaches the sound-letter correspondence. The combined stimulus procedure typically tested 2 to 4 sets of novel blends.

General Sequence

Learners progressed through the adduction sequences (oddity from sample and combined stimulus procedures) in the order determined by the overall instructional sequence (Layng, Twyman & Stikeleather, 2004), as follows:

- Establishing routine for **s**
- Establishing routine for *an,* then oddity *n*
- Establishing routine for *cl* then oddity for *c, l*

[3] Depending on where in the program the discovery (adduction) activities occurred, other procedures that established "seeing the phonetic elements, then saying the sounds," may have preceded the adduction units, but did not do so on a consistent basis.

- Establishing routine for *fr,* then oddity for *f, r*
- Combined stimulus procedure for *sn, cr, sl, fl*
- Establishing routine for *ip,* then oddity for *p*
- Combined stimulus procedure for *pl, pr, sp*
- Establishing routine for *t*
- Combined stimulus procedure for *tr, st*

Data Collection

Every response made by each learner was recorded and uploaded to the Headsprout servers. For all learning objectives, data categories included: the stimulus presented, the response requested, the position of the target stimulus, the position of the stimulus actually selected, the stimulus selected, the targeted and obtained response latency, the opportunities to respond, the correct and incorrect responses per minute, and the overall percent correct per instructional unit and the entire lesson.

Data collection procedures included automatic identification of oddity and combined stimulus units ("computerized data tagging"), allowing for measurement of the dependent variables chosen for this study. Dependent variables for this study were the percent of: (1) correct selections of the oddity stimulus; (2) learners who did not make a single error when asked to choose the oddity stimulus; (3) discrimination selections of the newly learned phonetic element from the oddity routine; (4) learners who did not make a single error when asked to discriminate the newly learned phonetic element from the oddity routine; (5) first time selections of the combined stimulus; and (6) learners who did not make a single error when asked to choose the combined stimulus.

Results & Discussion

Individual Participant Data

The oddity-to-sample procedure. Figure 1 shows chronologically the probe and subsequent performance data for the oddity to sample procedure, as well as performance on discriminating the newly learned phonetic element from visually similar stimuli. The data indicate that most participants did not select the target phonetic elements during probe trials (represented by closed circles on the graph), and that following the oddity procedures the participants were highly accurate at discriminating constituent sounds from combined sounds without having been directly taught the constituent sound (represented by open triangles). Upon the narrator's instruction "Click on the sound that does not say...," all participants immediately correctly responded away from previously learned stimuli. In addition, as a result of hearing the new sound as a consequence to the correct selection (responding away), the participants reliably selected the new discrimination from an array of similar non-examples (represented by closed triangles).

The combined stimulus procedure. Figure 2 shows chronologically the probe and subsequent performance data for the combined stimulus procedure. Again, the data indicate that most participants could not select the target phonetic elements (represented by closed circles on the graph). However, after instruction bringing one behavior under the guidance of one stimulus and a different behavior under the guidance of another stimulus and combining the two separate stimuli into a single presentation, the participants were reliably able to select the new behavioral "blend" (represented by closed triangles).

Consumer Participant Data

The oddity-to-sample procedure. Data for each new sound taught by the oddity procedure are presented in Figure 3. The number of learners presented with each oddity opportunity is indicated in the figure. The first bar depicts the mean percent correct responding for the oddity response across all learners. The second bar depicts the percent of learners who did not make an oddity response error.

The percent correct for the initial oddity response ranged from 86% to 97%. The mean percent correct across all oddity opportunities was 93%. The percentage of learners who made no errors ranged from just over 89% to over 98%. The mean percent of learners who made no errors across all oddity opportunities was 84%. It is clear that the learners could easily distinguish the stimulus that was not the one previously learned, clearly indicating that they could readily discriminate the previously learned stimulus from another stimulus even though that stimulus was a part of a phonetic unit previously learned.

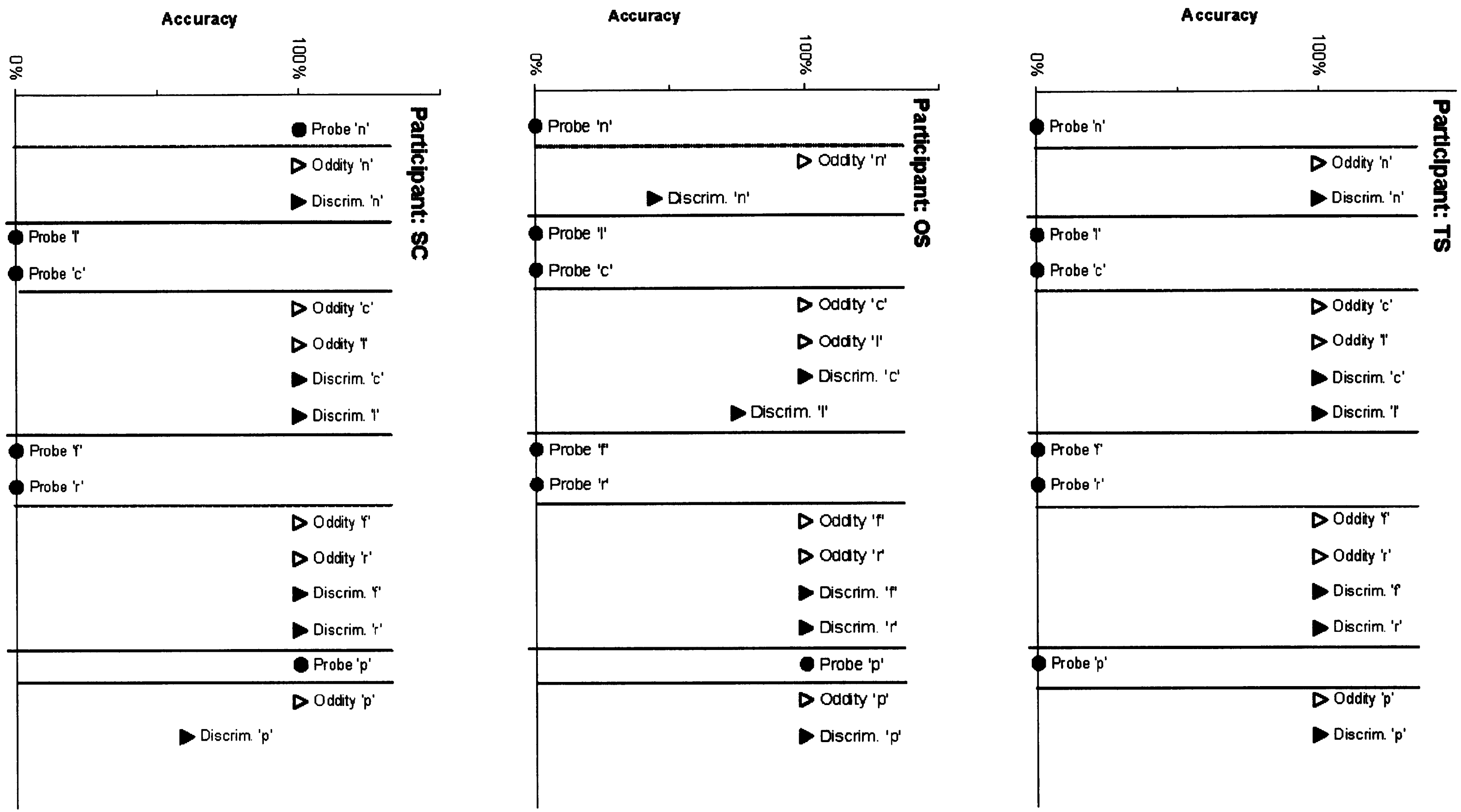

Figure 1. Sample individual participant data for the oddity procedure. Closed circles indicate probe conditions, open triangles indicate the initial oddity response, and closed triangles represent the percent correct for selecting the correct phonetic element from array of phonetic elements.

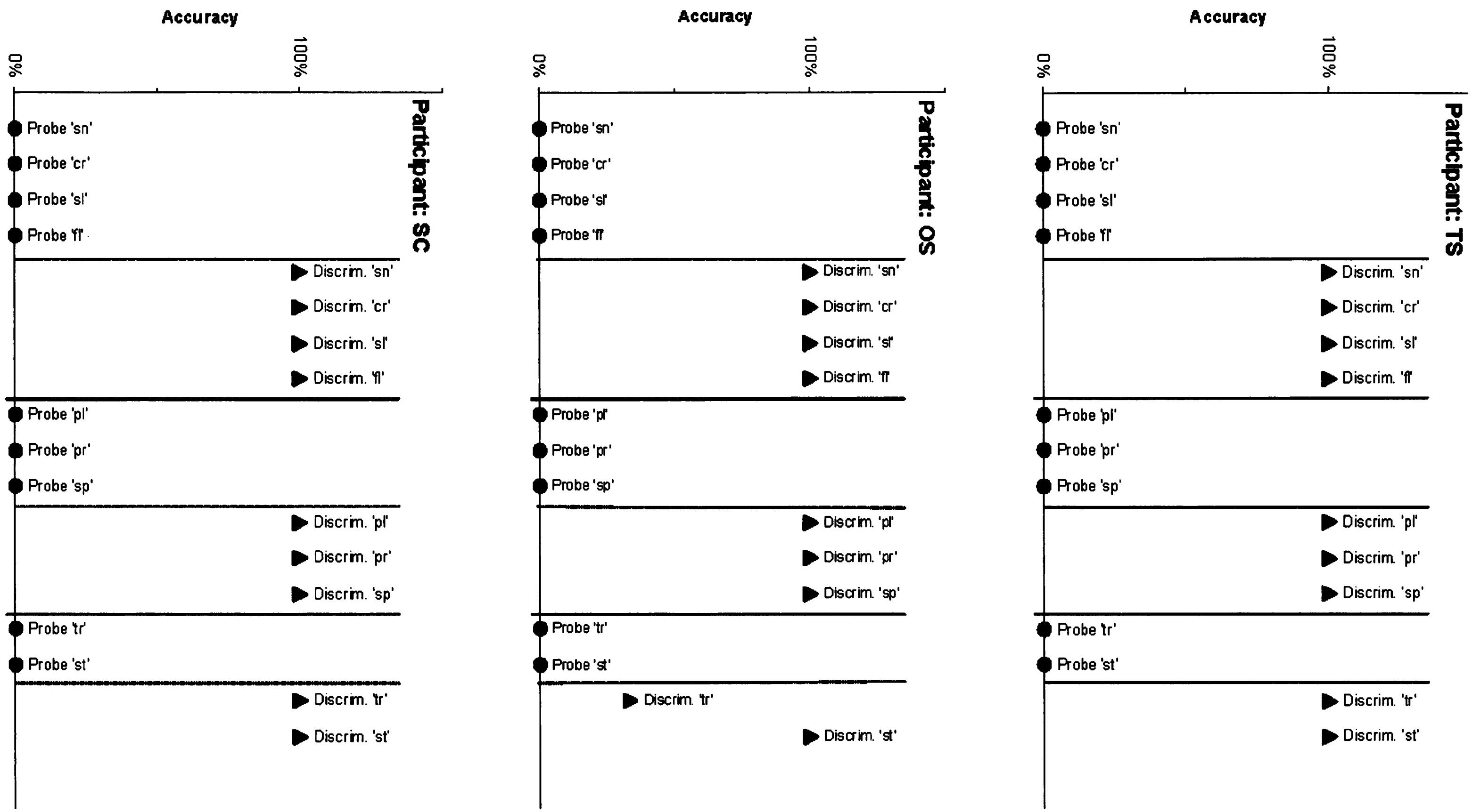

Figure 2. Sample individual participant data for the combined stimulus procedure. Closed circles indicate probe sessions, closed triangles indicate the percent correct for selecting the specified phonetic element from an array of phonetic elements.

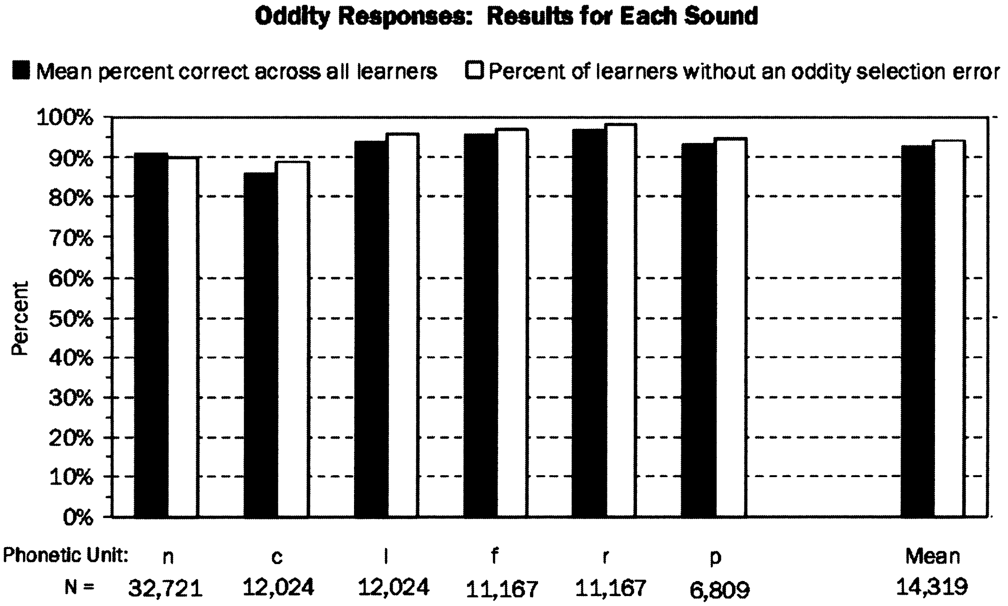

Figure 3. Mean percent correct for oddity responses across all learners (N), and percent of learners who did not make an oddity response error.

Figure 4 depicts the overall percent correct selections of the requested stimulus for the 6 oddity phonetic elements. These data include trials where the stimulus was presented in an array of 2 or 3 other phonetic units. On some occasions the learner was asked to click on one phonetic unit and upon other occasions, given the same array, a different phonetic unit —an example of conditional stimulus control. Trials continued until the learners emitted consecutive correct responses across all stimuli (intermixed). The data are reported for the target (newly learned oddity phonetic element). The mean percent correct for all 6 phonetic elements ranged from over 79% to over 90%, with a mean of 86% (when errors were made, these responses were corrected in as little as 2 to 5 trials). The percentage of learners who made no errors ranged from 82% to 90%, showing a tremendous number of learners performing the task without error and indicating the high degree of guidance exerted by these stimuli over the behavior of the learners. These results indicate that correct responding was immediately adduced by the oddity-from-sample procedure for nearly all learners without the need for a direct teaching sequence. When presented with a novel constituent sound and with no direct teaching, learners were able to choose the correct letter based on its sound and have that response confirmed, simply by responding away from the known discrimination.

The combined stimulus procedure. Data for each new sound taught by the combined stimulus procedure are presented in Figure 5. The number of learners presented with each combined stimulus opportunity are indicated in the figure. The first bar depicts the mean percent for selecting the combined stimulus for all learners. The second bar depicts the percent of learners who did not make any initial combined stimulus errors.

The mean percent correct for selecting the initial combined-stimulus ranged from over 74% to 93%. The mean percent correct across all combined stimulus opportunities was 82%. The percentage of learners who made no errors ranged from 77% to 95%. The mean percent of learners who made no errors across all combined stimulus opportunities was over 84%. It is clear that the most learners could easily select combined phonetic units that they had not before seen, indicating that they could readily blend the previously learned stimuli into a new stimulus unit.

General Discussion

This study systematically replicated (after Nueman & McCormick, 2002; Sidman, 1960)

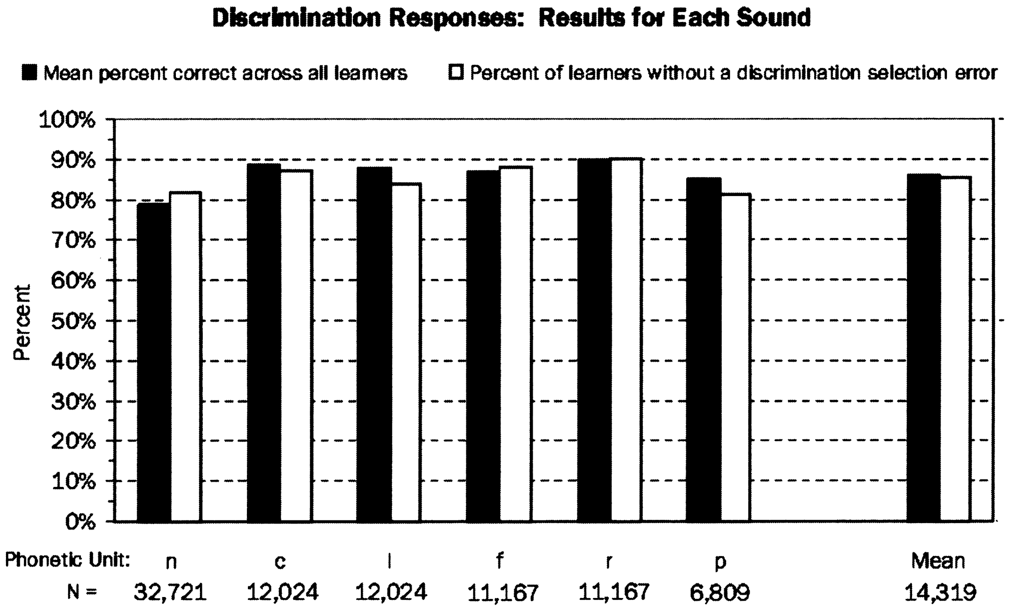

Figure 4. Mean percent correct for new discrimination responses across all learners (N), and percent of learners who did not make an discrimination response error.

results obtained in an entirely different context by Andronis, Layng, and Goldiamond (1997) for both the oddity-from-sample and the combined stimulus procedure. These results indicate that both the oddity-from-sample and the combined stimulus procedure were effective in demonstrating the contingency adduction of new skills important to building a decoding repertoire with little or no direct instruction. In contrast to the direct teaching sequence described in the "General Procedure" section above, the amount of instruction required for a new skill to be demonstrated using the adduction sequences was far less. Further, it provides evidence that suggests discovery-learning phonics sequences can be designed to have the same likelihood of success as a directly taught phonics sequence.

This study not only provides evidence from the performance of the three learners in the controlled evaluation study that well engineered discovery learning environments can be successfully incorporated into beginning reading programs, but provides data from thousands of learners from schools and homes throughout the world that indicate this is a robust effect. Further it points out the role the Internet can play to not only provide content, but as a vehicle to assess and extend results obtained in the laboratory.

As noted elsewhere (Johnson & Layng, 1992), contingency adduction applied in an instructional context requires three critical components: (1) an instructional sequence that firmly establishes the constituent skills whose occurrence either or alone or combined with other skills are, (2) specially arranged environments (in this case, the oddity-from-sample and combined-stimulus presentations), and (3) a contingent consequence that serves to select this new skill set. These three components point to the critical nature of learner programmatic history and instructional sequencing (see Stikeleather & Sidman, 1990). However, what constitutes the minimal initial instructional sequence required to firmly establish the constituent skills in order to facilitate their candidacy for contingency adduction, and thus, successful discovery learning; the range of specially designed environments that could occasion targeted skills; and the types of consequential events that can select new skill sets or combinations, were not addressed, but are all fertile areas for further research.

The data reported here suggest that the use of carefully designed programs that employ opportunities for contingency adduction can maintain a high level of effectiveness, while providing a discovery environment that allows the learner to encounter frequent "Aha!" ex-

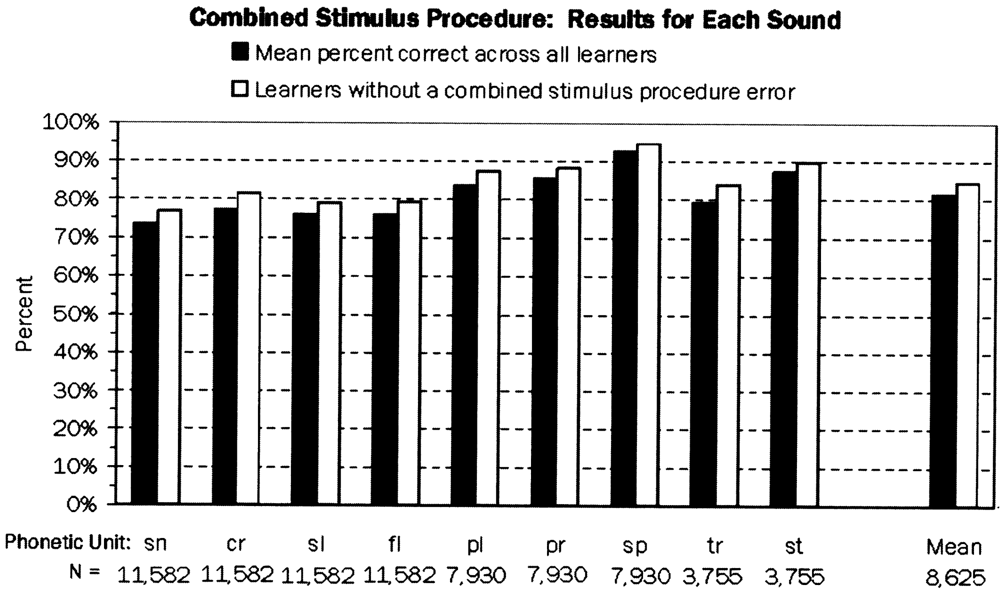

Figure 5. Mean percent correct for the combined stimulus procedure for each new sound across all learners (N), and percent of learners who did not make a combined stimulus response error.

periences during phonics instruction. Further, it systematically replicates earlier experiments using similar procedures for obtaining contingency adduction, and extends it to a new class of behavior, namely, those precursors important in the establishment of textually controlled verbal behavior. The success generated by these experiences may well lead to a general tendency to try and solve other new problems encountered while learning to read. Whether or not this is the case, however, must also await further research.

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