ABSTRACT

DISTINCTIVE FEATURES OF LETTERS AND ALPHABET ACQUISITION

by Meghan Kathleen Noonan

Distinctive features of letters is a prominent theory of letter recognition that proposes individual components of letters are separated and then detected individually in order for a person to recognize the letter. The purpose of this study was to locate existing articles that contain distinctive features lists. A systematic review of the research was conducted to find studies involving theories of distinctive features of letters. This research review led to identification of six articles. I applied data concerning alphabet learning and correlated it with distinctive features identified with a previous analysis. Significant correlations between the letter order theory and letters that slant were found, which suggests a relationship between distinctive features and the order in which children acquire the alphabet. These findings have implications for identifying differences in readers with and without dyslexia.

DISTINCTIVE FEATURES OF LETTERS AND ALPHABET ACQUISITION

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Introduction

Many scholars have investigated theories explaining the methods in which letter recognition takes place. One prominent theory often discussed is the distinctive features of letters. Distinctive feature detection can be defined as the theory that states specific components of letters, called distinctive features, are separated from the stimulus and then detected individually in order for letter recognition to take place (Naus & Shillman, 1976). The distinctive feature theory provides an explanation for how individuals receive visual input and then process that to encode it in their mind as a particular letter. Gibson (1969) was a strong supporter of the theory and believed that perceptual learning required the learning of individual distinctive features. Thus, the foundational aspect of letter-learning would depend on a specific letter's distinctive features.

Distinctive Feature Theories

A great deal of foundational research supporting distinctive features of letters was completed in the mid to late twentieth century. Perhaps one of the earliest studies involving the importance of distinctive features of letters originated from Gibson and colleagues (1962). The researchers examined how children ages 4 through 8 years of age develop the ability to visually discriminate letter-like forms. Rather than analyze the total number of errors children made on a given visual letter task, the researchers sought to analyze what type of errors were most frequent. For the experiment, the researchers first performed their own analysis of printed uppercase letters. From the analysis, they determined their own set of rules for the make-up of letters in order to create new forms of symbols. Twelve of these symbols were altered using 12 different types of transformations, chosen intuitively, such as rotation by three different degrees, symbol reversal, tilting, perspective transformation, and many others. Then, the subject completed a matching task with the transformations and standard symbols. In general, they found that the difficulty of discrimination for the children was determined by the type of transformation of the stimuli's distinctive features. Additionally, errors decreased as the subjects age increased, illustrating that discrimination improves during this period of 4 through 8 years of age due to better responsiveness of these distinct letter features.

Briggs & Hocevar (1975) used the list of distinctive features proposed by Gibson et al., (1962) to determine whether distinctive features can predict a pattern of confusions in a confusion matrix. By taking the number of features in common and dividing them by the total number of features, a degree of confusability could be established between different letter pairs. As a result, the researchers found that a pattern could be established. The results of the experiment revealed that if the letter pairs had more features in common, the more confusable the letter pair was.

Research directed at the distinctive features of visual object recognition also provided more understanding concerning distinctive feature analysis and the theories that supported it. Notably, Biederman (1987) developed the "recognition-by-components" (RBC) theory, which suggests that perceptual recognition of objects is fundamentally a process in which the visual stimuli becomes separated at its core and stripped down to a collection of basic geometric features. More specifically, Biederman asked how object recognition performance would be affected with the alteration of a given feature of that object. In one experiment, subjects identified line drawn three dimensional objects with the vertices or midsegments removed. In this case, Biederman found that object recognition was more negatively impacted by removing the vertices than by removing the midsegments. The theory of RBC and Biederman's findings are significant, especially for the theory of distinctive features. However, because letters are two dimensional, not three dimensional, Lanthier, Risko, Stolz, and Besner (2009) extended Biederman's 1987 study to include letter and word recognition. Over a series of four experiments, the researchers supported Biederman's (1987) object recognition results in finding that the removal of vertices from letters is more detrimental to letter and word recognition than the removal of midsegments from letters.

Likewise, Petit and Grainger (2002) and Rosa, Perea, and Enneson (2016) attempted to discover which components of letters are significant during letter perception, using a masked prime paradigm with partial letter primes. Petit and Grainger (2002) developed three different experiments in which stimuli consisted of 18 uppercase letters and 18 new symbols and were each preceded by a different type of partial prime of the letter: junction, midsegment, global, or neutral. Junction primes contained pixels at the meeting points of two lines; midsegment primes consisted of pixels at points between the junctions; global primes contained pixels randomly distributed throughout the letter's lines; and neutral primes consisted of pixels distributed randomly across the space that an entire version of the prime would inhabit. In experiment one, the researchers found that it was easier to identify the letters when they were preceded by a global prime, rather than a junction or neutral prime (midsegment primes were not included in experiment one). In experiments two and three, the researchers found that the target letters benefitted the most when preceded by a midsegment prime over the targets preceded by a junction prime. Rosa et al. (2016) continued this investigation using words as stimuli, instead of letters. Using two lexical decision experiments with lowercase stimuli, each target was preceded by one of four forms of a partial preview. The word identification time was shorter when the terminals-deleted partial preview was shown. This suggests that the terminals are the least important component, because when they were deleted from the word, the word identification time was similar to the whole preview condition partial preview.

Pelli, Burns, Farell, & Moore-Page (2006) initially wanted to complete a study to disprove feature detection theory, in favor of the template matching theory. In their study, they examined how individuals ages 3 through 68 years identify letters by measuring what contrast was needed in order to identify a letter presented in visual noise. They used an identification task, where the participant had to identify which letter signal had appeared on the screen in front of them when given a choice of all the letters of the alphabet. They also used a detection task, where the participant was presented with either a letter or a blank. The threshold contrast that was used to identify letters in noise produced a ratio of identification and detection. This ratio was part of a feature detection model that examined reciprocal relation between efficiency and complexity. They found that together, the ratio of identification to detection and the feature detection model suggests that identifying 1/26 letters is based on 7 +/- 2 feature detections. In other words, because the efficiency measures suggested that humans use comparable internal estimations for letter identification across settings, the feature detection model was able to produce a model that predicts approximately how many features are used. Thus, though the researchers originally sought to challenge the feature detection theory, the results suggest that the average reader is constrained and forced to identify by features.

The visual system was explored using a “Bubbles” technique with letter identification. A “Bubbles” technique (Gosselin & Schyns, 2001) can be used to determine specific visual information used when categorizing any given stimuli. The principal reasoning for implementation of Bubbles is the concept that masking the necessary visual information of an image will lead to an impaired performance on an identification task. Conversely, when the necessary visual information is revealed, it will lead to better performance. Fiset et al. (2008) used the Bubbles technique with letters, with the aim of learning which specific components of letters are necessary for their identification. In the study, six adult readers completed an identification task with 26 lowercase and uppercase letters, randomly sampled, in Arial font. Each of the letter stimuli were divided up into five spatial frequency scales. An opaque mask then covered the stimuli, except for the “bubbles” which were Gaussian holes placed at random on the letter. A multiple linear regression was then performed in order to determine the section of the letter that was critical for letter recognition, and the location on the spatial frequency scale. The researchers found that the most effective visual information was shown between the spatial frequency of 4 cycles per letter. In addition, the researchers completed a feature analysis using common features found in literature, and terminations. Results from this analysis showed that for a human observer, the line terminations were the most critical feature for recognition in both uppercase and lowercase font. The researchers created a computerized ideal observer model to consider how humans participants use letter features in comparison to a perfect model that included the best feature information. The ideal observer model engaged in an identical experiment as the human observers, with an equivalent feature analysis. The results of the feature analysis for the ideal observer model were different than for the human observer model. For example, terminations were most useful to humans, yet were in the sixth place for ideal observers. Fiset and colleagues (2008) suggested this was a result of constraints on the human visual system. These findings indicate that distinctive features of letters are a factor in letter recognition, although human factors account for a range of variability. That is, distinctive features alone cannot predict letter recognition difficult.

Letter Learning in Children

In addition to distinctive feature detection theories, there are questions about the potential developmental role distinctive features play in children’s identification of letters: Do current distinctive feature theories support letter-learning theories in young children? How do children learn letters? Justice, Pence, Bowles, and Wiggins (2006) examined four hypotheses regarding the order in which young children learn alphabet names. These four hypotheses were 1) Own Name Advantage: children will learn the letters that occur in their first name earlier than other letters, with the strongest being their first initial; 2) Letter-Order: children will learn the letters that are positioned earlier in the alphabet before the letters that are positioned later in the alphabet; 3) Letter-Name Pronunciation Effect: children will learn the letters that contain their pronunciation in the name of the letter; 4) Consonant Order: children will learn the letters that parallel the early acquired phonemes in infants and toddlers, before the letters that parallel the later acquired phonemes in children. By using a cross sectional design study, the researchers examined data from two sets of letter name knowledge assessment results of 4-year-old children. They found that the Own Name Advantage hypothesis was the most supported theory, with the Consonant Order theory the second most supported. The Letter-Order Hypothesis was modestly supported, with the most supported letters being A (beginning) and Z (end). The Letter-Name Pronunciation Effect also was modestly supported by empirical evidence. The results suggested that there are both external and internal factors that affect a child's learning of letters at a young age. Internal factors are unique to each child, such as the child's initials. External factors are universal, such as letter order, letter-name pronunciation, and consonant order.

Phillips and colleagues (2012) attempted to examine the internal and external letter learning factors through the use of Item Response Theory (IRT). IRT is a type of item analysis that specifically studies the patterns in responses to an individual item during evaluation of numerous individuals. IRT explores whether an item's responses are a result of the respondent's abilities and behaviors, or a result of the item itself. In the study, the researchers analyzed the letter-name knowledge data from various archival studies involving pediatric letter-name measures. To calculate IRT values for preschoolers' letter naming, participants were recruited from two large samples, one in Florida, and one in Texas. The children were shown a card with an uppercase letter (Florida) or uppercase and lowercase letter pair (Texas) randomly, and subsequently asked to name each of the randomly shown letters. The child participants' individual responses to each of the 26 items were analyzed using IRT with responder parameters and item parameters. The responder parameters looked specifically at how an item correlated to the responder's own latent abilities (i.e., internal factors). The item parameters looked specifically at the features of each item. These parameters are of importance to the present study, as they also represent external factors of letter learning. The item parameters used in Phillips and colleagues (2012) study were item difficulties and item discriminations. Children were shown a visual of each letter and asked to name the letter. Difficulty scores corresponded to the percentage of correct responses for that item. Discrimination scores corresponded to the degree to which each item could be differentiated from the participants' latent ability level. Ultimately, the goal of the study was to investigate whether there was a specific sequence in which children developed letter name knowledge. Results indicate that there is a fairly predictable sequence in the early and late stages of letter acquisition. For example, the letters A, B, O, and C are easier acquired than the letters V and U, which are two of the most difficult. A consistent sequence is not clear in the middle of the data. However, the researchers found there is a range of likelihood of being known for each letter. The difficulty and discrimination values from the item parameters make it possible to compare this data with distinctive feature detection data. Therefore, there is the potential to have a deeper understanding on how distinctive feature theory may impact children and the way they learn letters.

Current Study

The goal of the current study is to synthesize current research on distinctive features of letters used for perceptual recognition and discrimination. Much work has been done on the topic of letter perception in adults and children. Nevertheless, these theories have yet to be explored through a developmental lens. Theoretical and empirical evidence indicates the typical sequence of alphabet acquisition in young children. This study will explore whether theories of distinctive features are supported by developmental evidence of alphabet acquisition. This will be accomplished by conducting a systematic review of research involving theories of distinctive features of letters to identify prominent features that are used in perceptual recognition and discrimination. We will then use correlational analyses to measure how two theories of alphabet acquisition (Justice et al., 2006; Phillips et al., 2012) correlate with groups of letters based on their distinctive features.

Method

The systematic review portion of this research project followed procedures recommended by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al. 2009).

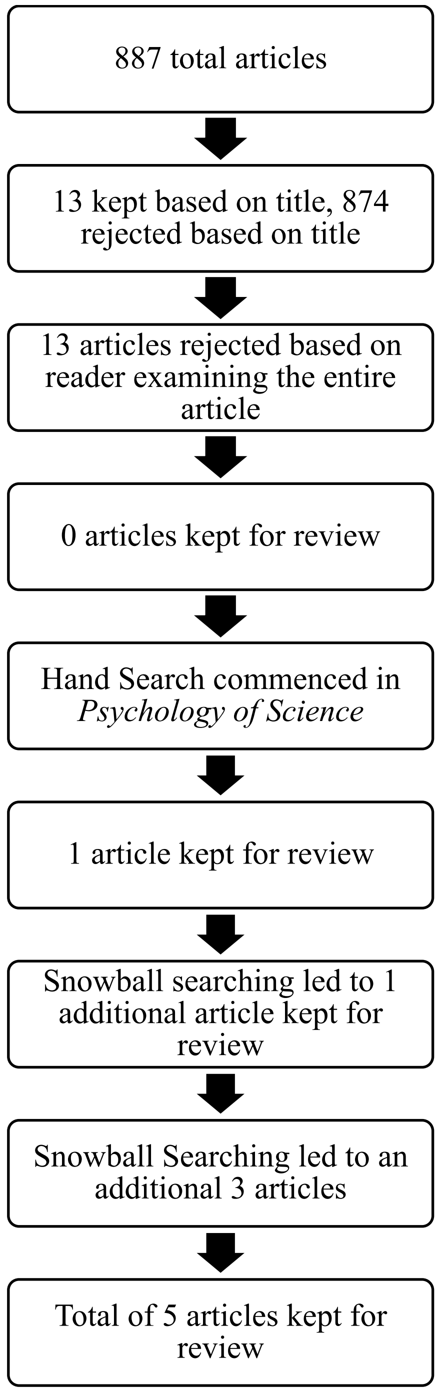
Eligibility Criteria, Information Sources, Search, and Study Selection

The first aim of the current study was to find and collect various theories of distinctive features of letters. We expected the review would include a small number of articles, given the limited number of articles found while reviewing the literature, prior to the formal search. Criteria for inclusion and exclusion of articles was decided prior to the search. Foremost, we included articles that involved a type of feature analysis of letter, since that was the goal of the systematic review. Furthermore, we only included articles that examined letters of the English alphabet. Articles that only examined the letters of the non-English alphabet and articles that only examined non- alphabet symbols were excluded. We included articles that involved populations of children through adults. Gray literature was not included in the search, and because of the long date since publication, previous authors were not contacted. Because of the limited nature of the research, date and year of publication was not a factor for inclusion or exclusion in the review. All articles were required to be published in English.

The databases searched for the systematic review were Ebsco and Clarivate. Specifically, *Ebsco- PsychINFO*, *Ebsco-Academic Search Complete, Ebsco- CINAHL, Ebsco- SocINDEX, Ebsco-Psychology and Behavioral Sciences Abstracts, and Clarivate- Web of Science.* These databases were chosen due to the frequent occurrence of letter feature studies that were found while reviewing literature for the project. Additionally, the Miami University Health and Sciences librarian, Anna Liss Jacobsen provided recommendations concerning the databases and journals in which to search. Following an initial search with the previously assembled Boolean phrases, 880 articles were found within the Ebsco databases, and 7 articles were found in the Clarivate-Web of Science databases. The Boolean phrases entered were: (letter* OR alphabet OR grapheme*) AND ("feature analysis" OR "distinctive analysis" OR "distinctive feature* analysis" OR "feature detection" OR "feature discrimination") AND (pattern OR recognition OR visual OR bubbles OR identification) AND (children OR adults). Each article title was read and selected based on whether it fit the inclusion or exclusion criteria. Specifically, titles were included that contained the keywords: letters or alphabet or graphemes; and distinctive features, feature analysis distinctive pattern, visual pattern, visual, identify, or recognition. Subsequently, 13 articles remained after narrowing by title. A depiction of the article identification chart is outlined in Figure 1. Each abstract of the remaining articles was read and included based on the exclusion and inclusion criteria. Four articles remained and were read in total. However, none of the remaining articles included a feature analysis list. Note that many of the distinctive feature analyses occurred in early journals, and thus a hand search was also conducted in the journal of *Psychology Science.* This journal was chosen due to its appearance in early searches in the

Figure 1

Article Identification Process



literature. From this search, one article was found, and narrowed by title and abstract. Because it satisfied exclusion and inclusion criteria, it was read in total, and included. Snowball searching was conducted from this article and another citation was found which also satisfied the inclusion and exclusion requirements. From this article, three citations were discovered, and subsequently included. In total, five articles were analyzed as part of the systematic review portion of the project. The objective of the article review was to present the distinctive features of each. As a result, each of the distinctive features found within the articles are organized in Table 1.

Articles

The systematic review portion of the research project yielded five articles of distinctive features of letters. The first article analyzed was Briggs and Hocevar (1975). The intent of the study was to predict the relative confusability of uppercase alphabet letters by using visual similarity analyses. Hence, the researchers used a distinctive feature list in order to predict the pattern of confusions in different confusion matrices. The indices of confusability within the distinctive feature setlist was correlated with the number of confusions in the seven confusion matrices. To create a distinctive feature list, the researchers discovered feature lists found in Gibson, Shapiro, & Yonas (1968), Kuennapas (1966), and Laughery (1969), and concluded there were four basic features of the uppercase letters in the alphabet: horizontal linearity, vertical linearity, angularity, and curvature, with many subdivisions which are displayed on Table 1.

Kuennapas (1966) was excluded due to the study being conducted with the Swedish alphabet. Gibson et al. (1968) decided that there were five basic features of uppercase letters, based on hierarchical clustering conducted with data from latency times in letter discrimination: Curve vs. straight, diagonality, vertical vs. horizontal, intersection, and relatively closed (round) vs. open. Although the features were determined based on a hierarchical method displaying distinguishing features, it should be noted that this study only used 9 pairs of letters.

Geyer and Dewald (1973) examined three different lists of features of uppercase letters in order to determine whether each had the capacity to predict an empirically based confusion matrix. In addition, the researchers analyzed the different methods of studying recognition processes that were employed to establish the feature sets. Therefore, the failure of a feature set to predict an empirical confusion matrix could then be accredited to flaws in the feature set itself, rather than flaws in the theory of feature processing. Feature sets from Gibson (1969), Laughery (1971), and Geyer (1970) were included in the study.

Gibson's (1969) (reported in Geyer & DeWald, 1975) final feature list included 12 features based on the 26 uppercase letters. According to Gibson, the features were developed primarily based on the experimenter's own intuition and were reinforced by pieces of literature meant to justify the selection. Gibson created four criteria for the feature list. To summarize, the features had to be present in some letters but not others (critical), relational, able to generate a unique pattern, and be reasonably economical. The 12 features included in Gibson's set can be seen in Table 1. Laughery (1971) (reported in Geyer & DeWald, 1975) created a list of 20 visual features in uppercase letters, as part of a theory of short-term memory in a computer simulation model. He created the list of letter features based on assumptions of features represented in uppercase letters, based on processes that are foundational to feature recognition.

Geyer (1970) (reported in Geyer & DeWald, 1975) created a feature list based upon Gibson's (1969). However, Geyer's list included certain adjustments due to his theory of metacontrast masking, or the importance of attention on a defined segment of the visual stimuli. Both Geyer's (1970) and Laughery's (1971) distinctive feature lists can be found in Table 1.

The feature list found within Fiset et al. (2008) and Fiset et al. (2009) was selected in order to correlate data between alphabet acquisition and letter-learning theories. The first reason this list was chosen was because Fiset and colleagues' (2008 and 2009) feature list included features found in the other studies that were reviewed. Both articles found 10 features thought to be important in the identification of uppercase letters, which can be found in Table 1. Fiset et al. (2008) examined uppercase and lowercase letters, and Fiset et al. (2009) examined solely uppercase letters. In addition, the studies both contain a more rigorous design than the other studies in the review. For example, Fiset et al., (2008) and Fiset et al. (2009) both employed the use of the *Bubble*s technique with letters in order to find the components responsible for identification. Fiset et al. (2009) additionally incorporated the use of multiple linear regressions on response accuracy and space-time samples. The Fiset and colleagues (2008 and 2009) studies are of importance because they examined letter identification from a visual-perceptive angle rather than only using a confusion matrix with hierarchical clustering. The Fiset and colleagues' (2008 and 2009) articles were the most recent of the articles reviewed, included a more comprehensive examination of letter features, and also examined which of those letter features may be more important than the others.

Alphabet Acquisition

The second aim of this study was to use the distinctive features of uppercase letters found in the systematic review and correlate this information to alphabet discrimination and difficulty data found within Phillips et al. (2012). Additionally, the data would be examined in relation to two prominent letter-learning theories (Justice et al., 2006): Consonant Order and Letter Order. The letters of the alphabet were coded in several ways. First, each letter had a discrimination value and a difficulty value from Phillips et al. (2012). Then, each letter of the alphabet was coded on whether it belonged to one or both of two prominent theories of letter learning found in Justice et al. (2006): Letter Order hypothesis, and Consonant Order hypothesis. For the Consonant Order hypothesis, the letters of the alphabet were ranked 1-26 from A-Z. It should be noted that the letters were coded for Consonant Order based on two theories of Consonant Order in children: Shriberg (1993), which includes the widely-known theory of 8 early, 8 middle, and 8 late consonants; and Sander (1972), which was used in Justice et al. (2006) and includes six categories of consonants based on order of acquisition.

Data Analysis

To examine the relationship between distinctive features identified by Fiset and colleagues (2009) and the difficulty and discrimination data by Phillips and colleagues (2012), we created a Pearson correlation matrix using SPSS (v.24). For each distinctive feature identified by Fiset and colleagues (2009), each letter was coded for number of those features it contained. Number of distinctive features were coded for each letter and correlated with the difficulty and discrimination values for each letter (Phillips et al., 2012). Variables that correlated with a $p < .05$ were considered significant.

To examine the relationship between the distinctive features (Fiset et al., 2009) and the Letter Order hypothesis (Justice et al., 2006), we ran a Spearman's rho correlation matrix. Number of distinctive features were coded for each letter and correlated with each letter's position in the order of the alphabet. Spearman's rho was used in lieu of a Pearson correlation due to the ordinal variables associated with Consonant Order. To examine the relationship between the distinctive features (Fiset et al., 2009) and the Consonant Order hypothesis (Justice et al., 2006), we conducted another Spearman's rho correlation matrix. We included the consonant ordering used by Sander (1972) and by Shriberg (1993). With both matrices, variables that correlated with a $p < .05$ were considered significant.

Results

Systematic Review

A systematic review was conducted to locate the distinctive feature lists. The review resulted in six feature lists which can be viewed in Table I. Note that all of the studies, with the exception of Fiset et al., (2008), utilized uppercase letters in their feature analyses. Fiset et al. (2008) analyzed both uppercase and lowercase letters. For the purposes of the present study, uppercase letters were applied. The organization of Table 1 highlights the many similarities in features identified across articles. For example, each article included features related to horizontal segments, vertical segments, curves, and slants or diagonals.

Table 1.

Articles and Features Found in Review

Fiset et al. (2008) and Fiset et al. (2009)	Laughery, 1971 *(found in Geyer & DeWald, 1973)*	Geyer, 1970 *(found in Geyer & DeWald, 1973)*	Gibson, 1969 *(found in Geyer & DeWald, 1973)*	Briggs & Hocevar (1971)	Gibson, Shapiro, & Yonas (1968)
1. Horizontals	1. Horizontal Top 2. Horizontal Middle 3. Horizontal Bottom	1. External Horizontal 2. Wedged, Horizontal 3. Bar-Horizontal 4. Open Horizontal	1. Straight Horizontal 2. Discontinuity: Horizontal	1. Horizontal Top 2. Horizontal Center 3. Horizontal Bottom 4. Single Vertical	1. Vertical vs. Horizontal
2. Verticals	4. Vertical Left 5. Vertical Center 6. Vertical Right	5. External Vertical 6. Wedged, Vertical 7. Open Vertical	3. Straight Vertical	5. Double Vertical	
3. Curves Opened Left 4. Curves Opened Right 5. Curves Opened Bottom 6. Curves Opened Top	7. Full Curve, Open Left 8. Full Curve, Open Right 9. Full Curve, Closed 10. Half Curve, Open Left, Top 11. Half Curve, Open Right, Top 12. Half Curve, Open Left, Bottom	8. Convex Segment	4. Open, Vertical Curve 5. Closed Curve 6. Intersection Curve 7. Open, Horizontal Curve	6. Small Curve, Convex Right 7. Small Curve, Convex Bottom 8. Large Curve 9. Continuous Curve 10. Closed Curve	2. Curves vs. Straight 3. Relatively Closed (round) vs. Open
7. Slants Tilted Right 8. Slants Tilted Left	13. Full Slant, Positive 14. Full Slant, Negative 15. Two Slants, Parallel 16. Part Slant, Positive 17. Part Slant, Negative	9. Slant Up Right 10. Slant Up Left 11. Internal Protrusion 12. Bar- Slant, Crossing	8. Straight Diagonal Right 9. Straight Diagonal Left 10. Cyclic Change 11. Symmetry	11. Angular, Open Top 12. Angular, Open Down 13. Angular, Open Horizontal	4. Diagonality
9. Intersections	18. Intersection	13. Intersection, Internal	12. Discontinuity: Vertical		5. Intersection
10. Terminations		14. Symmetry, Vertical 15. Symmetry, Horizontal			

Alphabet Hypotheses

A Pearson correlation matrix was produced for the IRT variables difficulty and discrimination (Phillips et al., 2012), which relate to children's learning of the alphabet. Other variables in the matrix included the features identified by Fiset and colleagues (2009). See Table 2 for the matrix. Significant correlations were found between difficulty and curves open to the left $r(25) = -.454$, $p = .020$. A negative correlation between difficulty values and curves open to the left means that letters with curves to the left are more difficult to learn. A significant correlation was also found between discrimination and slants right $r(25) = -.673$, $p < .001$, and between discrimination and slants left $r(25) = -.417$, $p = .034$. A negative correlation between letters that slant left and letters that slant right and the discrimination values means that letters with slants to the left and slants the right are more difficult to discriminate.

Table 2

Pearson Correlation Matrix for IRT of ABCs

Feature	Difficulty	Discrimination
Terminations	.329	-.107
Horizontals	-.252	.256
Slants Right	.009	-.673*
Intersections	-.253	-.132
Curves Left	-.454*	.033
Curves Top	-.028	.106
Slants Left	.014	-.417*
Verticals	.078	.228
Curves Bottom	-.028	.106
Curves Right	-.227	-.004

We produced a Spearman's rho correlation matrix to measure the correlation between the Letter Order hypothesis (Justice et al.,2006) and the distinctive features identified by Fiset et al. (2009). Significant correlations were found between letter order and slants right $r_s = .442$, $p = .024$, and between letter order and slants left $r_s = .419$, $p = .033$. A positive correlation with slants right and slants left and letter order means that letters with slants to the right and slants to the left were learned later according to the Letter Order hypothesis (Justice et al., 2006).

Table 3

Spearman Correlation Matrix for Letter Order Hypothesis

Feature	Letter Order
Terminations	.177
Horizontals	-.387
Slants Right	.442*
Intersections	-.209
Curves Left	-.137
Curves Top	-.029
Slants Left	.419*
Verticals	-.259
Curves Bottom	-.029
Curves Right	-.171

Finally, we produced a Spearman's rho correlation matrix to measure the correlation between the Consonant Order hypothesis (Justice et al., 2006) and the distinctive features identified by Fiset et al. (2009). We included the consonant ordering used by Sander (1972) and by Shriberg (1993). A significant correlation was found between intersections and Consonant Order proposed by Sander (1972), $r_s = -.549$, $p = .028$. A negative correlation with intersections and Sander's (1972) Consonant Order hypothesis (Justice et al., 2006) indicates that letters with more intersections are learned earlier (Justice et al., 2006). A significant correlation was also found between verticals and Consonant Order proposed by Sander (1972), r_s = -.677, p= .004, and between verticals and Consonant Order proposed by Shriberg (1993) r_s = -.512, p= .036. A negative correlation with verticals and Sander's (1972) and Shriberg's (1993) Consonant Order hypothesis indicates that letters with more verticals are learned earlier according to Consonant Order hypothesis (Justice et al., 2006).

Table 4

Spearman Correlation Matrix for Consonant Order Hypothesis

Feature	Sander (1972)	Shriberg (1993)
Terminations	.079	.137
Horizontals	-.161	.013
Slants Right	.193	-.014
Intersections	-.549*	-.402
Curves Left	-.298	-.276
Curves Top	.339	.320
Slants Left	.058	.026
Verticals	-.677*	-.512*
Curves Bottom	.339	.320
Curves Right	-.058	.082

Discussion

The present study examined distinctive features of letters in relation to developmental theories of alphabet acquisition. A systematic review of the literature was conducted in order to locate existing articles that contain distinctive features lists. After conducting the review, six feature lists found within five studies were recorded (see Table 1). The features that were found in the lists varied but had many similarities. For example, each list contained designated features that referred to a form of horizontals, verticals, and curves. Some of the articles were more extensive than others and contained more unique features, such as terminations, symmetry, and cyclic change. For the purposes of correlating distinctive features with alphabet acquisition theories, we selected the distinctive feature list found in Fiset and colleagues' 2008 and 2009 studies. This is because it included a more comprehensive examination of letter features and examined letter identification from a visual perspective.

The features included in the list were: terminations, horizontals, slants tilted to the right, intersections, curves opening to the left, curves opening to the top, slants tilted to the left, verticals, curves opening to the bottom, and curves opening to the right. The theories of how children learn letters, Letter Order theory and Consonant Order theory (Justice et. al., 2006), and the empirical discrimination and difficulty values for alphabet acquisition (Phillips et al., 2012) were then correlated with the Fiset and colleagues (2008 and 2009) feature list. We found several significant correlations, including a significant correlation between the Letter Order theory and letters that slant to the right and left, which suggests that a relationship is present between distinctive feature theories and alphabet acquisition theories.

Some correlations we expected to find were not significant. Specifically, Fiset and colleagues (2008 and 2009), emphasized terminations and horizontals as being the most important feature for human efficiency and ideal users, respectively. This corresponds with Petit and Grainger's (2002) study on different components of letters, where midsegments (similar to horizontals) were found to be important for letter identification. However, it contrasts with a Rosa and colleagues (2016) who found that terminals may be the least important part of a word. Surprisingly, our results did not find a significant correlation between terminations and horizontals with the alphabet acquisition data. One potential reason for this contrasting data is that young children may use different distinctive visual features during alphabet recognition. If there is a difference in the visual features used for alphabet recognition in children compared to adults, it would be beneficial in developing new methods for letter learning.

Curves Opening to the Left

The results of the study demonstrate several points of significance. To begin, the letters that contained curves open to the left (B, D, O, P, Q, R) were correlated with the IRT item difficulty values. Recall that difficulty values were determined by a parameter that measured degree of difficulty for identification of each letter. The discrimination values specified to what power each item could differentiate itself between participants latent ability levels. Yet, the curves that open to the left were not significantly correlated with the IRT discrimination values. The difference in significance may suggest that while the letters containing curves opening to the left are not as difficult to learn, children may have difficulty distinguishing among them. This could perhaps impact children learning letters. If children are taught letters in an order based on how difficult they are, it would be important for the instructor to remember that the letters that have curves open left may be less distinguishable, and the strategy for teaching the letter may need to be modified accordingly. Based on the IRT values, the letters with curves opened to the left in order from least difficult to most difficult are: O, B, P, R, D, Q. In fact, the letter O was the least difficult out of all the letters in the alphabet. Interestingly, Fiset and colleagues (2008) found that curves opening to the left were highly useful to human observers, but the computerized ideal-observer model was inefficient in using curves open to the left. A priori analysis of a computerized ideal observer in Fiset and colleagues (2009) experiment also found that curves open to the left were the third most relative important distinctive feature for letter identification, with terminations and horizontals being the 1st and 2nd most important, respectively. Similarly, Fiset and colleagues (2008) also found that terminations, which are present in the letters P, R, and Q, are the most useful relative distinctive features based on real human observers' performances. Because three out of the six letters that open to the left also contain terminations, this may support both Fiset and colleagues' experiments in their proposition of the vital importance of smaller features such as terminations.

Verticals

Verticals were positively correlated with both the Consonant Order proposed by Sander (1976) and Shriberg (1993). There are 13 consonant-letter pairs which contain verticals: B, D, F, H, J, K, L, M, N, P, R, T, and Y. According to Fiset and colleagues (2008), the human observers demonstrated inefficient use of verticals, whereas the ideal- model used the verticals highly efficiently. The significant correlation between Verticals and Consonant Order is noteworthy because it connects the letter features to a developmental theory, which may contribute to the implication that the features children use in letter learning differs from the letter features used by adults. Additionally, it introduces the idea that the child may not rely solely on visual/perceptive information to recognize letters, but they may be using multisensory information such as auditory and proprioception skills that accompany the development of consonants. This is supported by research suggesting a influence of both auditory and visual information in phonological processing (Jerger, Tye-Murray, and Abdi, 2009).

Intersections

Intersections were positively correlated with the Sander (1976) Consonant Order theory. There are 16 consonant-letter pairs which contain intersections: B, D, F, G, H, K, L, M, N, P, R, T, V, W, Y, and Z. In Fiset's 2008 analysis, the intersections were placed as the fourth most important feature to human observers, and in the 2009 analysis, intersections were placed as the sixth most important feature. Note that between the 2008 and 2009 studies, intersections were the only feature to change positions in the hierarchy of most important distinctive features. The other eight features remained in the same position between the two studies, despite the two studies using different parameters. Sander's (1976) Consonant Order theory relies on the idea that consonants emerge in a pattern of early, middle, and late consonants. Longitudinally, children are expected to produce consonants in a particular order, and therefore at any two given points of time of a child's early years, their consonant inventory may appear to shift. Because the usefulness of the intersections shifted with different parameters, we speculate that it could be possible for children to correlate the intersections with the Consonant Order theory due to changes that occur in acquisition correlating with shifts in the visual perception.

Letters with Slants Tilted to the Right and Left

Letters that contained slants that titled to the right (A, K, M, V, W, X, Y, Z) and left (A, K, M, V, W, X, Y, R, S, N) were positively correlated with discrimination values from the IRT variables. Furthermore, slants tilted to the right and slants tilted to the left were positively correlated with the Letter Order hypothesis from Justice and colleagues (2006).

Because slants to the right and left were correlated with both the IRT discrimination values and the Letter Order hypothesis, this may provide support for Justice and colleagues (2006) theory of the letter order. Justice and colleagues found that letters in the beginning half of the alphabet (A-M) had a slight advantage over the second half of the alphabet (N-Z). Furthermore, each letter was 1.02 times more likely to be known than the letter that proceeded it, and consequently the letter A was 1.5 times more likely to be known by the child participants than the letter Z. It is important to note that slants to the right and left contain the same letters, with the exclusion of R, S, and N slanting only to the left, and Z slanting only to the right. Fiset and colleagues' 2009 priori analysis found that slants to the right and left were the fourth and fifth most important features, respectively, concerning relative importance of the ten distinctive features. Why would slants be of importance in discrimination of letters and in the Letter Order hypothesis? Slants to both the right and left were not correlated with the Consonant Order hypothesis. Perhaps as Fiset and colleagues (2009) propose, the human visual system is constrained by itself, and not constrained by stimuli. This might support why the features children observe may be different than the adult human observers in Fiset and colleagues' studies. Children would neither be ideal human observers nor adult human observers. Potentially, humans may correlate different features at different critical time periods for the emergence of alphabet acquisition. Additionally, letters that slant tilting to the right and left both tend to contain intersections, with the exception of the letter S. Intersections were negatively correlated with the Sander (1976) Consonant Order hypothesis (Justice et al., 2006), meaning letters with intersections were more likely to be learned later according to the Consonant Order hypothesis. If the majority of letters with slants tilted to the right and left have intersections, this may further support why they are more likely to be learned later.

Limitations

There are several notable limitations to this study. Primarily, due to the COVID-19 pandemic and the inability to use human subjects, the data utilized in the correlational analyses with letter features and alphabet acquisition was provided from secondary sources. Additionally, the search resulted in a limited number of articles containing distinctive features lists. The majority of the feature lists, excepting Fiset and colleagues (2009), were based on confusion matrices from 50 to 60 years ago. In an ideal longitudinal analysis these experiments could be performed with younger children, so that the data could be more consistent. In the present study however, data from studies involving young children was compared to data involving adults, which is not preferable. Additionally, the letter data would be considered limited, due to there being 26 letters in the English alphabet. For the purposes of this study, one Pearson's and two Spearman's rho correlational analyses were performed.

Future Directions and Clinical Implications

Future studies examining the distinctive features of letters with alphabet acquisition should include an experimental study, so that alphabet acquisition in young children can be measured repeatedly at different developmental stages. Similar to Phillips and colleagues (2012), letter name recognition measures should be taken to track alphabet acquisition. Additionally, an ideal study would include a similar experiment to Fiset and colleagues (2009) to be used with children. In addition to the English alphabet, alphabets from other languages around the world could be incorporated into this study in order to determine if the features that are important are universal. In addition, a second study could be performed with an adult population to replicate Fiset and colleagues' (2009) study with multiple alphabets. The results of these studies could be compared to see how the letter features that are important to children differ from the letter features that are important to adults, and if there is a developmental stage during or after alphabet acquisition when these features shift.

Research that connects distinctive features of letters with letter learning theories is a novel area that may change how professionals commence teaching the alphabet to children. If there are features that seem to be more important for children's visual systems than adults' visual systems, then research may be able to develop new, more effective methods for alphabet learning. Additionally, this data could be tested with children with literacy disorders, such as dyslexia. It may be possible that the features in letters which are important for children with dyslexia might not be important in neurotypical children. For example, in Fiset and colleagues' experiments, the visual method of *Bubbles* was used to identify specific visual feature information found in letters. The letter stimuli were covered with an opaque mask, except for various Gaussian holes that were placed on the letter at random. Visual methods such as *Bubbles,* used in Fiset and colleagues (2008 and 2009) studies, could conceivably be employed to measure the features that children use, which in turn may allow for children to be identified with literacy disorders at younger ages.

Although this study examined the features of letters and the effect on alphabet acquisition, it is important to remember that there are additional factors that may impact alphabet acquisition in children. These factors include different exposure to letters at early ages and different methods of alphabet instruction. As alphabet knowledge is one of the best predictors in learning how to read (National Early Literacy Panel, 2008), it is in the best interest for professionals to determine how to increase access.

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