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Review article

Why are digits easier to identify than letters?

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A B S T R A C T

Beginning with Dejerine's report of pure alexia in 1892, numerous researchers have noted that individuals with acquired impairments of reading may show spared digit identification performance. This digit advantage has also been found in unimpaired adult readers across a number of tasks, and five main hypotheses have been proposed to explain how it arises. In this paper I consider these hypotheses in the context of recent theories of a unified alphanumeric character identification system, and evaluate them according to relevant empirical evidence. Despite some promising findings, none of the hypotheses currently provide a sufficient explanation of the digit advantage. Rather than developing new hypotheses to explain a categorical difference between digit and letter performance, I argue that future work should consider factors that affect identification performance specific to individual characters.

1. Introduction

Much recent research has focused on the processing of letters and words, which form a major component of our daily lives. Less work has considered Arabic digits (0–9), which are also prevalent visual stimuli that we process with ease. As visual stimuli, digits and letters are fairly similar in form and consensus is emerging that identification processes are shared between the two character types (Grainger and Hannagan, 2014; Kinoshita and Lagoutaris, 2010; McCloskey and Schubert, 2014). These theories are backed by a growing body of evidence from normal and impaired readers supporting the similarity of digit and letter identification. In the face of these data and corresponding theories, it has also been noted that digit identification is often more accurate than letter identification, and many authors have proposed possible explanations for this phenomenon (Cohen and Dehaene, 1995; Holender and Peereman, 1987; Ingles and Eskes, 2008; Polk et al., 2002; Polk and Farah, 1998; Rath et al., 2015; Starrfelt and Behrmann, 2011). However, few of these explanations have been explored or tested. In this paper I consider hypotheses for the digit identification advantage, evaluating them with respect to relevant properties of the characters and within an alphanumeric character identification system.

1.1. Evidence for shared letter/digit processing

Evidence has accumulated over the past few decades for similarities of performance in letter and digit identification tasks. This evidence has come not just from unimpaired adult readers but also acquired and developmental dyslexia. From adult readers, the evidence is largely from partial report/Reicher-Wheeler tasks in which strings of random letters, digits, or non-alphanumeric symbols are presented (e.g., Collis et al., 2013; Hammond and Green, 1982; Tydgat and Grainger, 2009). After stimulus offset, participants report whether a probe letter was present, or report the letter in a post-cued position; either version of the task requires identity and/or position processing for the characters of the string. A large number of studies have found that performance (indexed by the shape of the serial position function) is similar for letter and digit strings (Chanceaux and Grainger, 2012; Collis et al., 2013; Duñabeitia et al., 2012; García-Orza et al., 2010; Hammond and Green, 1982; Tydgat and Grainger, 2009), and only one early study reported a difference between the two character types (Mason, 1982).

Single letter and digit identification in unimpaired adults was studied by Starrfelt et al. (2010). Adult participants were asked to name a single briefly presented and masked character (from the digits 0–9 and uppercase letters A-J). The characters were blocked by type and presented in random order. Performance (as visual processing speed) was found to be approximately equivalent for digits and letters (Starrfelt et al., 2010). Other researchers have used priming in the same/different match task and lexical decision task to demonstrate that letters and digits activate the same sets of visual features and show effects of visual similarity across character types, providing further evidence for shared identification processing (Kinoshita and Lagoutaris, 2010; Kinoshita et al., 2015; Kinoshita et al., 2013; Perea et al., 2008).

Similarities between letter and digit identification processing are

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also seen in individuals with dyslexia. There have been three reports of individuals with acquired dyslexia who have highly similar deficits in identifying both character types (Katz and Sevush, 1989; McCloskey and Schubert, 2014; Patterson and Wilson, 1990). The similarities concern identification error types, serial position functions, as well as cross-category substitution errors. Furthermore, in a sample of five individuals with pure alexia studied by Starrfelt and colleagues (Starrfelt and Behrmann, 2011; Starrfelt et al., 2010, 2009), all showed impaired performance relative to controls on letter and digit identification tasks (four also showed numerically lower performance with letters than digits). In developmental dyslexia, there has been one report of a severe letter-identification deficit which also affected digits (Brunsdon et al., 2006).[1] Furthermore, a large group study of children with developmental dyslexia performing a partial report task also reported comparable performance for letter and digit stimuli (Ziegler et al., 2010), as did a study of adults with developmental dyslexia (Collis et al., 2013).

1.1.1. Shared letter and digit identification theories

The convergence of data from various lines of research onto the conclusion that letters and digits share an identification system is highly persuasive, and three research groups have posited theories with this property. The earliest theory is by Norris, Kinoshita, and colleagues (Norris et al., 2010; Norris and Kinoshita, 2012), who describe a model of letter identification as an instance of general object recognition. Kinoshita and Lagoutaris (2010) made a more specific claim: Letter and digit stimuli directly compete, activating both letter and digit identities due to their shared visual features. No distinction is drawn between letter and digit identification in this system. The second theory of a shared alphanumeric identification system, posited by McCloskey and Schubert (2014), includes a level at which visual features are represented, a level at which stored visual forms (allographs) are represented, and finally a level of character identities, with concurrent access to category information. Though category information is available within the system, the authors posit that it does not affect identity processing. Finally, Grainger and colleagues (Grainger et al., 2016b; Grainger and Hannagan, 2014) also suggest that letters and digits are recognized by the same process, contacting position-dependent character identities ('alphanumeric detectors'). By contrast to the other models, Grainger et al. (2016a) posit that letter and digit processing diverges prior to any position-invariant representations of character identity. However, the earliest stage of the model makes no distinction between letter and digit stimuli.

Though the details of these three theories differ, the basic assumption of a shared identification system is present in all of them: Digits and letters are identified in the same system without distinction based on the category of the stimulus. One major finding that seems to challenge shared alphanumeric identification is the alphanumeric category effect in visual search. This effect refers to searches for a different-category target (e.g., digit among letters) being more efficient than searches for a same-category target (e.g., digit among digits) (e.g., Egeth et al., 1972; Jonides and Gleitman, 1972; Polk and Farah, 1998; Taylor, 1978). The alphanumeric category effect has been taken as evidence for an at least partially segregated character identification system (Hamilton et al., 2006; Polk and Farah, 1998). However, the alphanumeric category effect can be accounted for without separate letter and digit identification by positing that category information is extracted in parallel with identity information (McCloskey and Schubert, 2014; Taylor, 1978).

Given the premise of shared identification processing without regard to category, it would be simplest to assume that digit and letter identification would be performed with equal accuracy and speed. However, this is not necessarily the case because identification may depend on characteristics such as frequency of occurrence, visual similarity of the stimulus to other characters, and the influences of downstream processing via feedback. The shared alphanumeric identification theories have not been implemented to the level of comparing letter and digit identification accuracy. This is in part due to a lack of knowledge about the effects of these variables, but also reflects the difficulty of modelling the full range of human identification performance for letters and digits across size, case, font, handwriting style, and other sources of variability in the input (e.g., Chang et al., 2012; Finkbeiner and Coltheart, 2009). In fact, empirical evidence suggests that digits often enjoy a speed or accuracy advantage in identification.

1.2. The digit identification advantage

Though a large body of work, reviewed above, suggests that letter and digit identification are similar, other findings suggest that digits may be easier to identify in some contexts. Individuals with dyslexia as well as unimpaired readers have been found to identify single digits faster and/or more accurately than single letters in a variety of tasks.

The main body of evidence for the digit identification advantage is from cases of acquired reading impairment. Possibly the first evidence was reported in 1892 by Dejerine (as translated and discussed by Bub et al. (1993)); the individual he described was poor at recognizing single letters but succeeded at recognizing single digits. A similar observation is commonly reported in studies of acquired dyslexia, where letters are often affected more severely than digits (e.g., Cohen and Dehaene, 1995; Deloche and Seron, 1987; Greenblatt, 1973; Grossi et al., 1984; Ingles and Eskes, 2008; Larsen et al., 2004; McCloskey and Schubert, 2014; Perri et al., 1996). In a review of 90 cases of pure alexia, Starrfelt and Behrmann (2011) reported that these individuals generally have an impairment in both single letter and single digit processing, though letters tend to be more impaired. They found no dissociations in which a clear digit identification impairment was found in the face of intact letter identification. And finally, a recent paper by Rath and colleagues (Rath et al., 2015) confirms that digit naming impairment with intact letter naming has not been reported in the aphasia literature. They also present new evidence that an advantage for digit processing over letter/word reading was present in a large unselected sample of individuals with aphasia (Rath et al., 2015).

According to these studies, and to my knowledge, there have been no reported individuals with impaired digit identification in the face of intact letter identification. However, there are a few cases of digit naming impairment which may be instructive. For example, Cipolotti (1995) report the case of SF, who was severely impaired in naming multi-digit numbers, but showed normal reading performance. It is interesting to note that only a small proportion (14%) of SF's errors in number naming were classified as lexical errors (e.g., 54 as 'thirty-four'); the majority were syntactic errors (e.g., 54 as 'forty-five') or combination errors (e.g., 54 as 'forty-three'). Lexical errors could arise due to misidentification of the digits in the stimulus, while syntactic errors reflect correct identification of the digits but a failure in constructing the appropriate syntactic frame for the verbal number response (Dehaene, 1992; McCloskey, 1992). The combination of intact letter identification (as reading) and a majority of digit errors which are not based in identification suggests that selective deficits to digit processing arise after identification, and hence after letter and digit processing have diverged.

The digit identification advantage has also been found in adults without reading impairment, typically as a speed advantage. Ingles and Eskes (2008) compared letter and digit identification performance of one individual with acquired dyslexia to five control participants with brain damage but unimpaired reading. All of these participants completed an attentional blink task requiring identification of two

[1] Though developmental dyslexia and developmental dyscalculia have been found to dissociate (Butterworth, 2005; Landerl et al., 2009), neither generally entails a deficit in letter or digit identification, except in particular cases discussed here (e.g., Brunsdon et al. (2006) and possibly: Shalev and Gross-Tsur (1993)).