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Research report

# Multicolored words: Uncovering the relationship between reading mechanisms and synesthesia

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ABSTRACT

Grapheme-color and lexical-color synesthesia, the association of colors with letters and words, respectively, are some of the most commonly studied forms of synesthesia, yet relatively little is known about how synesthesia arises from and interfaces with the reading process. To date, synesthetic experiences in reading have only been reported in relation to a word's graphemes and meaning. We present a case study of WBL, a 21-year old male who experiences synesthetic colors for letters and words. Over 3 months, we obtained nearly 3000 color judgments for visually presented monomorphemic, prefixed, suffixed, and compound words as well as judgments for pseudocompound words (e.g., *carpet*), and nonwords. In Experiment 1, we show that word color is nearly always determined by the color of the first letter. Furthermore, WBL reported two separate colors for prefixed and compound words approximately 14% of the time, with the additional color determined by the first letter of the second morpheme. In Experiment 2, we further investigated how various morphological factors influenced WBL's percepts using the compound norms of Juhasz, Lai, and Woodcock (2014). In a logistic regression analysis of color judgments for nearly 400 compounds, we observed that the likelihood that WBL would perceive a compound as bearing 1 lexical color or 2 lexical colors was influenced by a variety of factors including stem frequency, compound frequency, and the relationship between the meaning of the compound and the meaning of its stems. This constitutes the first study reporting an effect of morphological structure in synesthesia and demonstrates that synesthetic colors result from a complex interaction of perceptual, graphemic, morphological, and semantic factors.



## 1. Introduction

Synesthesia is a relatively rare phenomenon in which experiences in one domain or modality systematically lead to additional experiences in the same or different modality. For example, synesthetic individuals may experience tastes when hearing sounds (e.g., "expect" tastes like potato chips, Ward & Simner, 2003), colors when seeing letters (e.g., "H" appears yellow; Ginsberg, 1923), or tactile sensations when tasting foods (e.g., chicken feels prickly; Cytowic, 2002).

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Although some of the most commonly studied forms of synesthesia—grapheme-color and lexical-color synesthesia—are fundamentally based in reading, relatively little is known about how synesthesia arises from and interfaces with the reading process. Put another way, relatively little is known about synesthesia as a *psycholinguistic* phenomenon (Simner, 2007). Understanding the properties of reading-related synesthetic percepts could shed light on the nature of synesthesia, providing fine-grained information about the sorts of information and mental processes that give rise to these experiences. This information could also potentially inform psycholinguistic theories of reading by, for example, providing evidence in support of various hypotheses concerning the processes or representations involved in reading. In this paper we investigate the perceptions of an individual who experiences grapheme-color and lexical-color synesthesia, experiencing colors for letters and words when reading. His pattern of performance reveals that his color perceptions arise through a complex interaction of multiple levels of linguistic structure, indicating for the first time that synesthesia is intimately related to the functioning of the reading system. To situate this work, we first describe the architecture of the reading system and interpret existing research on grapheme- and lexical-color synesthesia within this framework.

### 1.1. *Word recognition*

Although psycholinguistic theories of reading differ in their specifics, there is general consensus about the primary stages of processing involved in word recognition. The first stage of processing is orthographic encoding, in which a retina-centered visual image is transformed into a word-centered string of letters. This process, which involves recognizing letters and their positions, is generally held to first involve the extraction of low-level visual features (e.g., | ∖ — /) that are combined into higher-level allographic structural representations representing the basic visual properties of the stimulus letter. Many theories hold that these structural representations are then mapped onto Abstract Letter Identities ('ALIs', sometimes referred to as 'graphemes'), which are theorized to encode the identity of a letter irrespective of its case, font, position, etc. (e.g., Brunsdon, Coltheart, & Nickels, 2006; Jackson & Coltheart, 2001; Schubert & McCloskey, 2013; see Rothlein & Rapp, 2014 for a review, and Plaut & Behrmann, 2011 for a differing position). As an example, 'e' and 'c' would have similar allographic (structural) representations but would map onto distinct abstract letter identities while 'e' and 'E', being visually dissimilar variants of the same letter, would have dissimilar allographic representations but would ultimately map onto the same ALI. Following orthographic encoding, the graphemic representation is used to retrieve the corresponding lexical entry from the orthographic lexicon, which in turn provides access to the word's semantic and syntactic information. The word recognition process can thus be roughly divided into three stages: 1) *pre-lexical*, involving information pertaining to visual form and letter identity, 2) *lexical*, involving word-level structure, and 3) *post-lexical*, involving the word's meaning and syntactic properties. Contemporary psycholinguistic theories generally hold that the reading process is interactive, which means that these stages of processing (and their sub-processes) influence each other (e.g., McClelland & Rumelhart, 1981). Activation is thought to cascade from one stage of processing to the next and may feed back from subsequent to earlier stages. This means that, for example, word-level properties such as frequency and neighborhood density can influence pre-lexical computations (such as letter recognition, e.g., Reicher, 1969) through feedback connections.

### 1.2. *Morphology*

A rich body of research has examined how morphologically complex words are processed during reading. Morphologically complex, or 'multimorphemic', words are words that are composed of multiple meaningful units, commonly referred to as 'morphemes'. In English, multimorphemic words comprise prefixed words (e.g., *re-visit*, *un-sub-titled*), suffixed words (e.g., *yawn-ing*, *hope-ful-ness*) and compounds, which are words that contain two or more lexical stems (e.g., *newspaper*, *balloon animal*). The consensus that has emerged from over 40 years of research is that morphologically complex words are decomposed during processing, meaning that the sub-components of a multimorphemic word are identified during processing and influence the way the word is processed (e.g., the processing of *newspaper* involves the recognition of *news* and *paper*; see Amenta & Crepaldi, 2012 for a review). Research also suggests that readers store whole-word representations for multimorphemic words, though it is debated whether this is true for all or only some multimorphemic words (see Lignos & Gorman, 2012 for a review).

Psycholinguistic theories of reading hold that morphological structure is represented at lexical levels. While the processing of a monomorphemic word would involve the retrieval of a single lexical representation (e.g., <AWNING>), multimorphemic words would involve the retrieval of two or more lexical representations (e.g., <YAWN><ING>). Evidence exists that morphological structure may exist at pre-lexical levels as well. Rastle, Davis, and New (2004) reported that in lexical decision tasks, pseudo-suffixed words prime their pseudo-stems to the same degree that truly suffixed words prime their actual stems. For example, *brother* and *gluten* provide just as much facilitation for *broth* and *glute*, respectively, as *viewer* and *soften* do for *view* and *soft*, respectively. Rastle and colleagues showed that this was not due to simple orthographic similarity (e.g., *brother* primed *broth* better than *brothel* primes *broth*). Since the word *brother* is monomorphemic (i.e., not *broth-er*), these results suggest that decomposition occurs on the basis of orthographic matches to lexical items in addition to true morphological/semantic relatedness. That is, the reading system at least temporarily considers *brother* to be morphologically complex since it can be divided into two independently existing letter strings.

Rastle et al.'s (2004) findings can be accounted for by a pre-lexical stage of decomposition. Under this account, letter recognition processes produce morpho-orthographically grouped representations (B-R-O-T-H and E-R) rather than simple strings of letters (B-R-O-T-H-E-R). These morpho-orthographic groupings may activate an incorrect set of lexical representations (e.g., <BROTH><ER>), which must then be