How does foveal processing difficulty affect parafoveal processing during reading?

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ABSTRACT

Models of eye movement control during reading assume that the difficulty of processing word n in a sentence modulates the depth of processing of the upcoming word/s (word $n + 1$) in the parafovea. This *foveal load hypothesis* is widely accepted in the literature despite surprisingly few clear replications of the basic effect. We sought to establish whether observing a foveal load effect depends on the type of parafoveal preview used in the boundary paradigm. Participants' eye movements were recorded in two experiments as they read sentences in which a low- or high-frequency word n—a typical manipulation of foveal load—preceded a critical target word. Prior to the reader making a saccade to word $n + 1$, the parafoveal preview was either identical to word $n + 1$; an orthographically similar word or nonword; or an unrelated word or nonword. The results revealed that the critical evidence for a foveal load effect—an interaction between word n frequency and word $n + 1$ preview—was limited to conditions in which the invalid preview baseline was an orthographically illegal nonword. The remaining conditions produced completely additive effects of the two factors. These findings raise questions about the mechanisms underlying the spillover of foveal processing difficulty to parafoveal words. The implications for theories of reading are discussed.

Introduction

Skilled readers extract lexical information not only from the word they are fixating (word n), but also from at least the upcoming word (word $n + 1$), located in parafoveal vision. Studies of eye movements during reading typically quantify parafoveal processing using the gaze-contingent *boundary paradigm* (Rayner, 1975) in which a preview stimulus occupies the location of word $n + 1$ until the reader's eyes cross an invisible boundary located at the end of word n. During the saccade that crosses the boundary, the preview is replaced by a valid presentation of the target word $n + 1$. Because the change occurs during a saccade, when vision is suppressed, participants are typically unaware of display changes. However, fixation duration on word $n + 1$ is reduced following a valid preview of that word, relative to a baseline condition in which the preview is invalid. This *preview effect* provides a diagnostic of the extent and depth of parafoveal processing.

Parafoveal preview effects

Preview effects have most frequently been assessed against a baseline preview of an orthographically illegal nonword—usually a string of consonants. This form of baseline seems a reasonable choice because it is unrelated to both the target and any other word in the lexicon, and thus prevents readers from extracting any useful information from the parafovea. However, the assumption that a consonant-string baseline is "neutral" is undermined by evidence that the presence of orthographic illegality in the parafovea disrupts foveal word recognition processes (Angele, Slattery, & Rayner, 2016; Hutzler et al., 2013; Kliegl, Hohenstein, Yan, & McDonald, 2013).

Preview effects are therefore composed of benefits from pre-processing word $n + 1$ in the valid or related preview condition, as well as costs associated with processing an orthographically unfamiliar string in the unrelated condition. The comparison of an identical preview to an orthographically illegal baseline typically yields a preview effect of approximately 35–40 ms on gaze duration (see Vasilev & Angele, 2017 for a review), which has been attributed to the costs and benefits associated with *trans-saccadic integration* of parafoveal and foveal information. Trans-saccadic integration is also the accepted explanation for preview benefits from word or nonword previews that are orthographically and phonologically related to word $n + 1$ (see Schotter, Angele, & Rayner, 2012 for a review).

However, recent research has provided evidence of a distinct form of preview effect that cannot be explained by trans-saccadic integration. Specifically, fixation duration on word $n + 1$ is affected by the ease of

Table 1
Summary of results of studies that manipulated word n frequency and word n + 1 preview.

Study	n	Word n frequency × Word n + 1 preview interaction	Invalid preview condition	Task	Notes
Henderson & Ferreira (1990) Exp 1	12	**Yes**	Consonant string	Reading for comprehension	
Kennison & Clifton (1995)	48	No[a]	Consonant string	Reading for comprehension	Interaction significant for subset of trials with saccades into word n + 1 at close launch sites
Schroyens, Vitu, Brysbaert, and d'Ydewalle (1999)	28	**Yes**	Scrambled pixel mask	Reading word triads to detect "clothing" words	
Drieghe, Rayner, and Pollatsek (2005) Exp 2	20	No	Illegal nonword	Reading for comprehension	Targets were 3-letter words; invalid preview replaced middle letter with x
White et al. (2005) Group 1	32	**Yes**	Consonant string	Reading for comprehension	Participants in Group 1 were unaware of display changes
White et al. (2005) Group 2	16	No	Consonant string	Reading for comprehension	Participants in Group 2 were aware of display changes
White & Liversedge (2006a) Exp 2	44	No	Illegal nonword	Reading for comprehension	Targets were 9- and 10-letter words; invalid preview replaced second letter to make illegal initial trigram
Drieghe, Rayner, and Pollatsek (2008)	28	No	Illegal nonword	Reading for comprehension	Invalid preview replaced second and third letter of target with consonants
Yan, Kliegl, Shu, Pan, and Zhou (2010)	74	**Yes**[b]	Unrelated word	Reading for comprehension	Chinese reading study; frequency was manipulated on word n + 1 and preview was manipulated on word n + 2
Liu, Reichle, and Li (2015)	32	No	Reference marks	Reading for comprehension	Chinese reading study
Veldre & Andrews (2015)	107	No[c]	Consonant string	Reading for comprehension	
Angele et al. (2016)	32	**Yes**	Legal/illegal nonword	Reading for comprehension + display change detection	Interaction did not depend on display change awareness
Marx, Hawelka, Schuster, and Hutzler (2017)	201	No	Visually degraded mask	Reading for comprehension	Participants were Grade 4 and Grade 6 children
Vasilev, Slattery, Kirkby, and Angele (2018) Exp 1	32	No	Illegal nonword/visually degraded mask	Reading for comprehension	
Vasilev et al. (2018) Exp 2a	16	**Yes**	Illegal nonword/visually degraded mask	Reading for comprehension + display change detection	
Vasilev et al. (2018) Exp 2b	16	No	Illegal nonword/visually degraded mask	Reading for comprehension + display change detection	

[a] A three-way Word n frequency × Word n + 1 preview × Word n + 1 frequency interaction was significant on FFD.

[b] Interaction was significant on FFD and marginally significant on gaze duration.

[c] Foveal load participated in higher-order interactions with reading and spelling ability. Supplementary analyses revealed that there were no significant Word n frequency × Word n + 1 preview interactions in models that did not include the individual differences variables.