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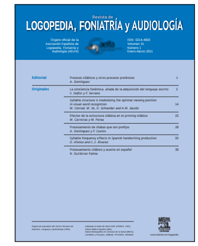

ORIGINAL ARTICLE

Syllable structure is modulating the optimal viewing position in visual word recognition☆

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Visual word recognition;
Perceptive identification;
Optimal viewing position;
Syllable structure

Abstract
There is an ongoing debate in cognitive psychology as to whether syllables have to be seen as functional units not only for speech perception and production, but also for the process of silent reading or visual word recognition. For the present study, we used a perceptive identification task where single disyllabic 5-letter German words were briefly presented to the participants for 50 or 60 milliseconds. The percentage of errors in identifying these stimuli was the dependent variable. During presentation in the experiment we manipulated the viewing position for these items, so that initial fixation for each repeatedly presented word varied systematically across all five letter positions. Typically, for such manipulations, word recognition is best when initial fixation is at a position slightly left from the word center — a finding referred to as the optimal viewing position effect. We found that the shape of the optimal viewing position function is sensitive to syllabic structure: The optimal viewing position shifted one letter position to the right with increasing initial syllable length (two vs. three letters in our stimulus material). This finding suggests that efficient reading benefits from a very early processing of syllabic information. It corroborates other recent empirical findings suggesting that also during silent reading orthographic word forms are automatically segmented into their syllabic constituents.

PALABRAS CLAVE
Reconocimiento visual de palabras;
Identificación perceptiva;
Posición de visualización óptima;
Estructura silábica

La estructura silábica modula la posición óptima de visualización en el reconocimiento visual de palabras

Resumen
Un debate actual en psicología cognitiva gira alrededor de sobre si las sílabas deben entenderse como unidades funcionales no sólo en la percepción y producción del habla, sino en el proceso de lectura silenciosa o en el reconocimiento visual de una palabra. Para el presente estudio, usamos una tarea de identificación perceptiva en la que se presentaban durante 50 o 60 ms

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palabras alemanas bisílabas de cinco letras a los participantes. Se consideró como variable dependiente el porcentaje de errores al identificar estos estímulos. Durante el experimento manipulamos la posición de visualización de estos elementos, de modo que la fijación inicial para cada palabra reiteradamente presentada variaba de forma sistemática en las posiciones de las cinco letras. Normalmente, en tales manipulaciones, el reconocimiento de palabras es mejor cuando la fijación inicial se ubica en una posición ligeramente a la izquierda del centro de la palabra; un hallazgo denominado efecto de la posición óptima de visualización. Encontramos que la forma de la función de la posición óptima de visualización es sensible a la estructura silábica: la posición óptima de visualización se desplazaba una letra a la derecha cuando la longitud de la sílaba inicial aumentaba (dos frente a tres letras en nuestro material de estímulo). Este hallazgo señala que la lectura eficaz se beneficia de un procesamiento muy temprano de la información silábica. Corrobora otros hallazgos empíricos recientes que indican que durante la lectura silenciosa las formas ortográficas se segmentan de forma automática en sus constituyentes silábicos.

Introduction

Language in general can be described as a symbolic system assigning specific meaning to single words or phrases. Proficient use of this system, the understanding and production of speech is normally acquired during the first years of childhood.

Reading and writing, instead, is normally not being taught to children before entering school around the age of six and it involves an additional level of symbolic transformation. Linguistic contents originally belonging to the domain of sounds are represented visually using a symbolic system; and in the case of alphabetic writing systems, the combination of about 30 little signs has to provide a sufficient level of differentiation to represent all words of a particular language in a distinguishable manner.

In contrast, some writing systems, like the Chinese, have maintained a relatively high level of direct symbolic relatedness between words and their written representations using single symbols for single words, the formal features of which relate to the semantic proprieties of the words they stand for. In theory it could be argued that something similar would hold true even in alphabetic writing systems: That words would be recognized as entire symbols directly assessing a word's meaning from its orthographic word form.

The luminous advertising of a hotel might in fact be perceived as an integral symbol when arriving at night in foreign city without having to encode the specific letters "H", "O", "T", "E" and "L". In addition, we are able to fluently read and correctly pronounce words from a text in a foreign language without knowing what the words mean or ever having seen them before, at least when we are familiar with the alphabet and the phoneme inventory of this language and when there is a consistent relation of the language's orthography to the latter one.

The focus of interest varies considerably between different scientific approaches investigating the reading process: Language in general and, of course, written language can be described on many different levels of decreasing grain size from entire texts over phrases and word levels to sublexical units — not to mention the role of single letters' visual features.

The experimental work presented here focuses on processes underlying the recognition of visually presented isolated words. Of course, single words are normally embedded in sentences with specific syntax and the syntactic structure of phrases is known to influence the reading process (see e.g., Friederici, 1995; Hoeks, Stowe, & Doedens, 2004; Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Rösler, Putz, Friederici, & Hahne, 1993). The processing of single words has also been shown to depend on the context they appear in as a function of predictability determined by preceding information within a sentence (see e.g., Dambacher & Kliegl, 2007; Dambacher, Kliegl, Hofmann, & Jacobs, 2006).

On the other hand, the processing of more complex structures like entire texts or phrases would be impossible without the efficient processing of single words being their basic constituents. And the question of how this basic process of accessing the meaning of single (isolated) words in visual word recognition is achieved by the human mind is still far from being completely resolved.

Sublexical units in visual word recognition

Whereas some words in some context may be recognized holistically, such an efficient direct access to an over-learned visual word form can not sufficiently describe visual word recognition in general. Assuming that lexical access does not always occur in a holistic manner leads to the question of which parts of a word — being referred to as sublexical units — would play which specific role in mediating the process of lexical access. In other words, what are the functional units of visual word recognition?

A wide range of theories and models — from verbal models to parallel distributed or localist-connectionist computational models — have been formulated or implemented to account for the process of lexical access in visual word recognition (see Jacobs & Grainger, 1994; Barber & Kutas, 2007, for reviews). These models do not only differ in their degree of specification, their general architecture or their computational principles; they also operationalize specific views on which sublexical units might be functional during visual word recognition.

One of the most demonstrative findings showing that orthographic or morphological processing alone cannot sufficiently describe all aspects of the process of visual word recognition is the "pseudohomophone effect" (see Ziegler, Jacobs, & Klüppel, 2001). Letter strings that do not match an orthographic word form, but sound like a word when being pronounced have been found to be relatively hard to correctly reject in the lexical decision task. This specific finding in the lexical decision task (see Rubenstein, Lewis, & Rubenstein, 1971) can only be explained when assuming that phonological encoding or internal pronunciation of the presented stimulus occurs even when no overt pronunciation is required by the task. In everyday life we can observe this phenomenon when somebody is moving his or her lips while reading a book.

From a theoretic perspective, it has been shown that phonological processing increases with the difficulty of lexical access (see, e.g., Conrad, Grainger, & Jacobs, 2007, reporting effects of phonological syllabic parsing only for low frequency, but not for high frequency French words in lexical decision). But it has also been described as an automatic feature of the reading process (e.g., Lukatela, Eaton, Lee, Carello, & Turvey, 2002; Frost, 1998; Van Orden, 1987).

The importance of phonological encoding during visual word processing – especially when the attempt of a fast direct access to an orthographic word form fails – is reflected in the architecture of an influential computational model of visual word recognition: The dual route model of visual word recognition and reading aloud (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Within the phonological route of this model, letters are matched onto graphemes and graphemes are converted into phonemes via the application of a grapheme-phoneme conversion rule before the whole phonological word form can be accessed as the combination of the word's phonemes (see also Jacobs, Rey, Ziegler and Grainger (1998) for an extension of the original multiple read out model (MROM, Grainger & Jacobs, 1996) now containing both orthographic and phonological sublexical units).

The role of syllabic units

Besides a word's phonemes, the basic phonologically defined sublexical unit comprising more than one phoneme or grapheme is the syllable.

On the assumption that words, or at least parts of words, are phonologically encoded or internally pronounced during silent reading, one might expect that a word's syllabic structure should influence the process of visual word recognition, because we cannot know how to pronounce a polysyllabic word form before we know which parts of it can be pronounced in a continuous stream.

Despite this rationale and during many years, evidence for syllables being functional units of the reading process was sparse and contested: Prinzmetal, Treiman and Rho (1986), for instance, reported that illusionary conjunctions were higher when two letters were part of a syllable than when they were not, but this finding was subsequently interpreted as possibly arising as a mere by-product of orthographic redundancy (Seidenberg, 1987, 1989, but see Rapp, 1992, Tousman & Inhoff, 1992, for additional evidence regarding the role of syllables during visual word recognition in English).

Generally, syllabic effects had been examined more extensively in the domain of speech perception and note that most of the relevant studies were based on Roman languages (e.g., Cutler, Mehler, Norris, & Seguí, 1986; Mehler, Dommergues, Frauenfelder, & Seguí, 1981; Morais, Content, Cary, Mehler, & Seguí, 1989).

The reason for the apparent lack of attention to the syllable in the domain of visual word recognition research might lie in the fact that most of this research had focused on the English language where – partially as a consequence of the inconsistent relation between spelling and sound – syllable boundaries are completely ill-defined. Instead of seeing the syllable per se as a functional reading unit, research on phonological processing during visual word recognition in English often concentrated on sub-syllabic units as e.g., syllabic onset, body, and rime (e.g. Taft, 1992; Treiman & Chafetz, 1987).

But the picture changed completely with two empirical studies undertaken in two Roman languages, Spanish and French reporting an inhibitory effect of syllable frequency on lexical access in Spanish (Carreiras, Álvarez, & de Vega, 1993) and a syllabic priming effect for naming latencies for visually presented French words (Ferrand, Seguí, & Grainger, 1996). Whereas the latter finding has turned out to be a much contested empirical report (see Perret, Bonin, & Meot, 2006; Brand, Rey, & Peereman, 2003; Schiller, 1998, 2000), an initial syllable frequency effect in lexical decision has already been replicated in two other orthographies: French (Conrad et al., 2007; Mathey & Zagar, 2002) and German (Stenneken, Conrad, Goldenberg, & Jacobs, 2003; Conrad & Jacobs, 2004; Conrad, Stenneken, & Jacobs, 2006), one Roman and one non-Roman language. But note that a recent attempt to replicate this effect in English has failed (Macizo & Van Petten, 2007). The pattern referred to as the initial syllable frequency effect in lexical decision describes the finding that words starting with a high-frequency syllable – a syllable that also forms the initial syllable of many other words – are responded to more slowly in lexical decision than words with low initial syllable frequency. The syllable frequency effect is generally interpreted as evidence for an automatic syllabic segmentation of visually presented words: after a syllabic segmentation of the input, the first syllable activates the representations of words sharing this syllable in identical position and competition between these is responsible for the observed delay in the processing of words with high-frequency initial syllables (e.g., Perea & Carreiras, 1998).

In addition, syllable frequency has been shown to influence neurocognitive correlates of the reading process, such as event related potentials (Barber, Vergara, & Carreiras, 2004; Hutzler et al., 2004) and hemodynamic responses (Carreiras, Mechelli, & Price, 2006). Findings like these are generally interpreted as evidence that the reading system is sensitive to words' syllable structure, probably using phonological syllables as functional units of the reading process (Álvarez, Perea, & Carreiras, 2004; Conrad, Grainger, & Jacobs, 2007).

For the present study we make use of another experimental paradigm in psycholinguistic research in an attempt to provide converging evidence for the assumption of automatic syllabic processing in visual word recognition.

Beside the lexical decision task (Rubenstein, Lewis, & Rubenstein, 1971), which is generally supposed to provide an indirect measure of the time necessary to achieve lexical access of a word, perceptive identification tasks are another class of paradigms designed to explore the mechanisms underlying the reading process.

In such experiments perception of stimuli is made more difficult than in normal reading, for instance by drastically reducing stimulus presentation time towards a subliminal threshold, and using the percentage of correct identifications as the main dependent measure. One of the main findings obtained for such manipulations — which determines the focus of interest for the present study — is the optimal viewing position effect: When measuring fixations in sentence reading experiments where participants' eye movements are recorded by an eye-tracker, the eye seems to land preferentially in positions slightly left to the middle of words (Dunn-Rankin, 1978; Rayner, 1979) — at least in a language like English that is read from left to right. Also for the French language, Vitu, O'Regan, and Mittau (1990) reported that re-fixations during sentence reading were the least probable to occur for positions slightly left from the center. A similar finding was observed by these authors when words were presented in isolation suggesting that there is a preferred viewing location slightly left from the center of words. But also recognition performance for isolated words were found to be sensitive to fixation position: when participants were forced by an experimental manipulation to fixate a stimulus word at a specific position, recognition performance was found to be best for fixation positions left from the center (e.g., O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984; O'Regan & Jacobs, 1992; McConkie, Kerr, Reddix, Zola, & Jacobs, 1989). This is generally achieved by instructing participants to fixate a fixation cross, which will subsequently be replaced by a briefly presented stimulus word whereby the stimulus' exact spatial position relative to the preceding fixation cross is varied as the independent variable. E.g., the word CENTRO would be fixated slightly left from the middle if the letter N (or also the letter E) would appear in the position previously occupied by the fixation cross.

The typical pattern of results is called the optimal viewing position (OVP) effect, which is characterized not only by the fact that performance is better when the centre of a word is fixated as compared to its edges, but also by an asymmetry in the resulting viewing position (VP) function: The VP function has its peak —corresponding to best performance— slightly at the left from the center of words (see Rayner, Well, & Pollatsek, 1980). Note that additional evidence for the apparent importance of this specific fixation position comes from the finding of prolonged durations of fixations of such letters situated slightly left from the centre of words. This pattern of results where letters appearing at optimal viewing positions receive especially long fixations is called the inverted OVP effect (Vitu, McConkie, Kerr, & O'Regan, 2001; Nuthmann, Engbert, & Kliegl, 2005). Apparently fixation durations increase in that case, because these specific fixation positions enable the reading system to gain more relevant information about the word being processed than when other letters are fixated.

A number of different hypotheses have been brought forward to account for these findings: Basic for all of them is the rapid drop in visual acuity with increasing distance from the center of vision (Anstis, 1974; Jacobs, 1979). According to O'Regan (1981), this explains why letters left or right from the fixation point are recognized less efficiently than those in the center. But why the asymmetry in the viewing position function?

Language processing in our brain is strongly hemispherically lateralized — with specialized areas within the left temporal lobe (at least for most individuals, see Brysbaert, 1994, for implications of possible changes of localization). The contra-lateral characteristics of the visual system produce information from the right visual field of both eyes (everything that is right from a fixation point) initially to be processed by the left hemisphere. This could be a reason why for most people fixating a word slightly left from its center should result in a processing advantage, because information in that case might most efficiently be transferred to language processing brain areas (see Brysbaert, Vitu, & Schroyens, 1996). Indeed Brysbaert (1994) reported somewhat inversed VP functions for individuals with apparent right hemisphere localization of language processing. Still, the difference between the two types of hemispheric dominance in that study was rather small.

Another possible reason for the asymmetry in the VP functions might be seen in the reading direction going from left to right in all languages the studies mentioned above have been conducted in. In fact, two studies run with languages read from right to left could show that this asymmetry disappeared when using Arabic words (Farid & Grainger, 1996) or even inverted resulting in a peak of the function right from the middle when Hebrew words were read (Deutsch & Rayner, 1999).

But in addition to these two types of theoretic accounts suggesting either general neurologic predispositions or general features of the writing system (left to right or right to left) as the source of the asymmetric VP function, another proposal — which could be called the lexical constraint — assumes that the properties of the words themselves could motivate the typical asymmetric shape of the VP function. O'Regan (1981) argued that the left rather than the right part of most words contains the more crucial information necessary for the extraction of meaning. Clark and O'Regan (1999) showed that functions of mean ambiguities calculated as a function of fixation position were highly similar to VP functions observed in prior research. Interestingly, Steven and Grainger (2003) showed that a measure of constraint based on relative position coding of letters generated relatively accurate predictions for VP functions. But in general, not much empirical data has been collected to examine the hypothesis that the maximum of the VP function could be modulated by the internal organization of words in addition or contrast to more general phenomena as, for instance, reading direction, visual span, or perceptive learning (Nazir, Deutsch, Grainger, & Frost 2000).

With the present study we want to test the hypothesis whether the syllabic structure of the word stimuli modulates the shape of the VP function. Assuming that syllabic processing is an automatic feature of the reading process, — as an increasing number of empirical studies from several languages suggest — even very early stages of processing as assessed by a viewing position manipulation might prove sensitive to syllabic structure. Precisely, if it is of importance for the reading system to "know" where syllabic boundaries in an orthographic word form are located, then the maximum of the VP function might be "attracted" to the position to these boundaries. The rationale for the present experiment therefore is to test whether the maximum of the VP function for five letter disyllabic German words will move from slightly left from the centre (the second letter) towards the center (the third letter) as a function of syllable boundary position in our stimuli.

Method

Participants

Sixty University students of the Katholische Universität Eichstätt-Ingolstadt and of the Freie Universität Berlin participated in the experiment. Their participation was rewarded with course credits. All participants were native speakers of German. They were invited to participate regardless of individual handedness. Note that no conclusions regarding hemispheric localization as potentially influencing OVP function should be drawn from our results (see Brysbaert, 1994).

Stimulus material and design

Sixty-four five-letter disyllabic German words were selected from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993), according to the manipulation of the factor length of the initial syllable (two vs. three letters). The following variables were controlled for across the two cells of the experimental design: Word frequency (20.64 mean occurrences per 1 Million of words; Std dev. 29.29 vs. 19.67 mean; 29.45 Std dev. for words starting with two-letter vs. words starting with 3-letter syllables), orthographic neighbourhood density (M 2.25; Std dev 2.48 vs. M 2.81; Std dev 2.28) and frequency (M 0.78; Std dev 1.31 vs. M 0.94; Std dev 1.29) (number of orthographic neighbours and number of higher frequency orthographic neighbours, see Andrews, 1997 for a review of respective effects in visual word recognition), positional token frequency of the first and second syllable (see Conrad, Carreiras, & Jacobs, 2008). Half of the initial syllables in each condition had a vowel offset, half ended with a consonant.

With the aim of word identification, each word had to be responded to by each participant five times in different fixation positions corresponding to the word's single letters. The experimental session for each participant comprised five different and consecutive blocks each containing all 64 stimulus words. Fixation positions were varied within each block balancing both (between) stimulus' experimental condition and (within stimulus) fixation position. All stimuli were once presented in each fixation position during the whole experiment. Order of blocks and order of appearance of items within blocks were randomized for each participant.

Apparatus and procedure

Stimuli were presented in uppercase letters using Courier 24 type font on a 17'' ProNitron color monitor (resolution 1024 × 768 pixel, 75 Hz) driven by an Umax Pulsar computer. Stimulus presentation and response recording was controlled by PsyScope software (V. 1.2.4 PPC; Cohen & MacWhinney, Flatt, & Provost, 1993). At the utilized viewing distance of 50 cm the stimuli subtended a visual angle of approximately 1.7 degrees. Each trial was initiated by a blank screen of 500 milliseconds (ms) duration followed by a fixation point appearing at the center of the screen for 500 ms. The fixation point was then replaced by the word stimulus. No visual mask was used after or before stimulus presentation. The stimulus remained visible only for either 50 or 60 ms. Note that people differ considerably in their individual capacity to process very shortly presented visual information. In order to increase the probabilities of ending up with a sufficient number of datasets characterized by individual overall error rates suitable for statistical purposes, we chose to apply these different alternative presentation durations. Participants were instructed to press a button as soon as they had an idea what the stimulus word had been and to enter their response (the stimulus) on the computer keyboard. After doing so they could start a new trial by pressing the return key. There were ten initial training trials. Participants were tested individually in a quiet room.

Results and analyses

Mean percentages of correct word identifications (see Figure 1) were submitted to separate analyses of variance (ANOVAs) by participants and by items (F1 and F2, respectively) testing for statistical significance of potential effects of syllabic structure (two vs. three letter initial syllables; within participants, between items manipulation) and fixation position (first vs. second vs. third vs. fourth vs. fifth letter; within participants, within items manipulation) and potential interactions between the two effects. Note that especially an interaction between the two main effects characterized by a shift of the peak of the VP function towards the right with increasing syllable length would indicate a specific early sensitivity of the reading system to syllabic proprieties of visual input. The data of seven participants were not included in the analyses as individual error rates were less than 7%. Note that an overall error rate of approximately 25% is considered optimal for statistical data analyses in such tasks when recognition performance is measured as percentage of correct identifications.

Analyses revealed a significant effect of fixation position on recognition rates for our stimulus words, $F1(4,52) = 68.78$, $P < .001$; $F2(4,62) = 93.34$, $P < .001$. The resulting VP function for all stimulus words showed the typical shape with recognition rates generally being highest in initial letter fixation position 2 and lowest in position 5. Correct response averages generally decreased towards the edges. Single tests for differences between single positions revealed significant results for all comparisons with the exception of those between position 2 and 3 and between positions 1 and 4 (all $P < .001$). No significant mean differences were obtained for the factor syllable length as a main effect. But importantly, the interaction between the two effects was significant, $F1(4,52) = 4.99$, $P < .001$; $F2(4,62) = 2.41$, $P = .04$. As evident from Figure 1, the respective VP functions for words with two letter initial syllables on the one hand, and for words

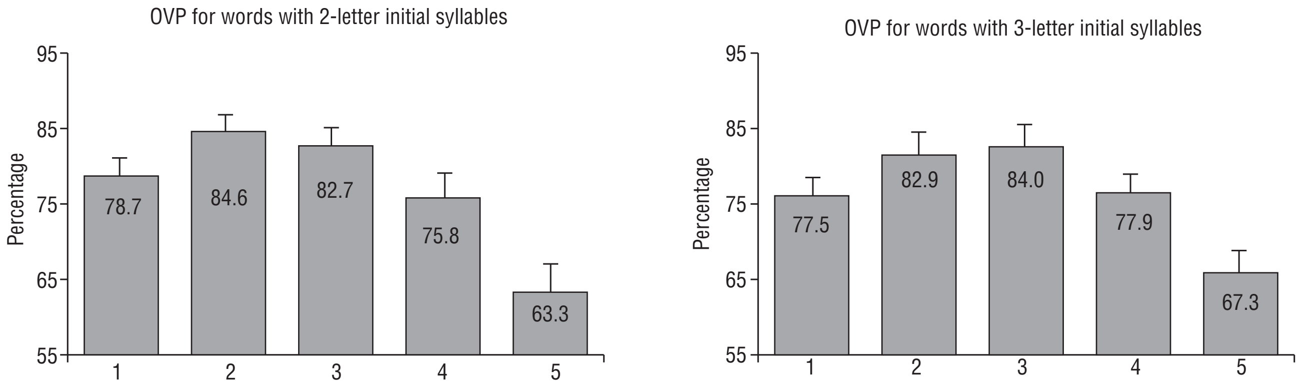

Figure 1 Mean correct recognition rates for words with different orthographic syllabic structure as a function of initial fixation position (corresponding to letters 1-5). Error bars are giving standard errors of means.

with three letter initial syllable on the other differ in shape, especially regarding their respective peak: performance was best for words starting with two letter syllables when the second letter was the one initially fixated. But performance was best for initial fixations of the third letter when words started with three letter syllables.

In order to verify whether it were indeed those fixations around the syllable boundary of our stimulus words which caused the significant interaction between the two effects of syllable length and fixation position, we conducted new ANOVAs focusing only on recognition rates for letter fixation positions two and three.

Doing so, as predictable from the single comparison results presented above, no significant effect of letter fixation position emerged between positions two and three. There was no main effect of syllable length either. In turn, the interaction between these two effects again reached statistical significance, $F1(4,52) = 4.96$, $P = .04$; $F2(4,62) = 4.52$, $P = .04$. It can therefore be concluded that the manipulation of syllabic structure/length shifted the peak of the VP function to the right with increasing syllable length.

Discussion

In an experiment where healthy student participants had to identify shortly flashed (50/60 ms) single disyllabic words, we found that correct recognition rates varied as a function of initial fixation position (each of the five letters of a stimulus word could be located in the centre of the screen) — replicating previous findings of a viewing position function with a peak slightly left from the centre. More importantly, our novel finding is that the exact location of this performance peak varied according to the syllabic structure of stimulus words. Participants recognized words most efficiently when the fixated letter was the final letter of the initial syllable (either the second or the third letter in the present material). But note that at the present state probably no reliable conclusions can be drawn regarding the question of whether intra-syllabic letter position (syllable onset, nucleus or coda) are relevant for the observed processing advantage. But still, even a more conservative interpretation of our data at least suggests that the point of best recognition was horizontally shifted towards the right with increasing length of the first syllable in disyllabic words. This again seems to be clear evidence that word recognition is enhanced when fixations are close to syllable boundaries.

Moreover, this data adds to the growing body of evidence in favor of a functional role for the syllable during visual word recognition. It provides important novel evidence from a perceptive identification task — converging with the broader range of lexical decision studies available so far on the topic (e.g., Carreiras et al. 1993; Conrad, Carreiras, Tamm, & Jacobs, 2009). The data also make an interesting contribution to the discussion on the source of the optimal viewing position effect. We could show that the shape of the VP function is indeed modulated by lexical or even sublexical phenomena. It has been proposed that the asymmetry of the VP function peaking left from the centre might be due to the fact that word beginnings generally carry more crucial information than word endings (Clark & O'Regan, 1999). Further developing this line of argument, our data shows a specific sensitivity of the VP function to syllabic structure. It seems that fixating words close to their syllabic boundaries provides a benefit for the reading system — probably because an automatic syllabic segmentation of polysyllabic words enhances phonological processing of these stimuli when fixation position corresponds to phonologically defined syllabic boundaries within the orthographic word form.

Finally, these findings might have important implications beyond the academic scope of cognitive psychology: If fixating a word's syllables helps healthy participants to identify words under extremely difficult task conditions (presentation duration of 50-60 ms) then people with reading impairment might also benefit from increasing their attention to words' syllabic structure and to syllabic representations in written words.

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