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Syllabic structures in typing: Evidence from deaf writers

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Abstract. This study examined the time course of typing in prelingually and profoundly deaf as well as hearing individuals. Both groups of participants performed a written picture naming task and a written pseudoword task. Keystroke timing measurements from the written picture naming task revealed that the deaf as well as the hearing group were significantly delayed at syllable boundaries compared to identical within-syllable letter combinations. As the deaf are impoverished with respect to phonology based on spoken language experience, we postulate that syllabic segmentation is not crucially dependent on experience with spoken language. Furthermore, delays at syllable boundaries were not affected by word frequency in both groups, in contrast to the keys straddling a root morpheme boundary. Together with the finding that delays at syllable boundaries also occur in pseudowords, the experiments provide strong evidence towards post-lexical syllabification processes. Our results support previous findings which claim that (1) orthosyllables are autonomous and mode-specific entities, and (2) that the principles of syllabic organisation apply post-lexically.

Key words: Deaf, Syllable, Orthosyllable, Writing, Typing

Abbreviations: IKI – InterKey Interval (the time between two successive keystrokes); L-IKI – an IKI straddling a letter boundary; S-IKI – an IKI straddling a syllable boundary; SM-IKI – an IKI straddling a syllable and a morpheme boundary

Introduction

Linguists have proposed that syllables play a crucial role in the phonological organisation of spoken languages (e.g., Blevins, 1995; Clements, 1990). This view has recently been carried over to sign language, suggesting that syllabic organisation applies independently of the physical means of a given language. For example, it has been argued that underlying principles of hierarchical organisation in sign language are similar to those of spoken language in that the syllable node branches into onset and rime and the rime into nucleus and coda. Also, these subsyllabic units respect the principle of sonority (see Brentari, 1995, for

ASL; Pfau, 1997, for DGS, Deutsche Gebärden Sprache (German Sign Language); for a review of neuropsychological and imaging data see Peperkamp & Mehler, 1999).

Another source of evidence for syllabic organisation is provided by studies on written language. One emerging view in literature is that graphemic representations in spelling encode more information than just the identity and order of letters. In studies on slips of the typewriter key it has been reported that writers had a tendency to preserve the consonant/vowel status in substitution errors (e.g., Grudin, 1983; Shaffer, 1975). The preservation of consonant/vowel status has been found in the error pattern of dysgraphic patients, too (e.g., Cubelli, 1991; Ward & Romani, 2000). Also, letter doubling seems to be encoded in written spelling (Caramazza & Miceli, 1990). These results suggest that graphemes – analogous to phonemes (the subsyllabic segments of spoken language) – are grouped into suprasegmental units, or: orthosyllables. Graphemic representations are, in this respect, organised in a similar fashion to their phonological counterparts, with auto- and suprasegmental levels or tiers. Most of the current models represent the graphemic structure on at least three different tiers located in the Graphemic Output Buffer: a graphosyllabic tier, a CV-tier, and a grapheme identity tier (Badecker, 1996; Caramazza & Miceli, 1990; Marini & Blanken, 1996; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Ward & Romani, 2000). The view of syllables as independent graphemic units is also supported by Domahs, de Bleser, and Eisenberg (2001) in a single case study of a German surface dysgraphic. The patient's errors in writing to dictation showed strong influences of autonomous suprasegmental processing governed by (grapho-) syllabic principles.

Recently, it has been argued that graphemic representations in spelling are, to a large extent, independent of spoken language (hypothesis of orthographic autonomy, Miceli, Benvegnu, Capasso, & Caramazza, 1997; Rapp, Benzing, & Caramazza, 1997). The current evidence for the hypothesis of orthographic autonomy is primarily based on case studies with dysgraphics suffering from phonological impairment. One might argue that the inability for oral spelling and/or the error patterns in written spelling do not necessarily imply the absence of spoken language phonology. But it has also been demonstrated, in a study with normal adults that the latency differences between oral and written naming did not differ in immediate and delayed conditions, arguing against an obligatory phonological mediation (Bonin, Fayol, & Gombert, 1998). Nevertheless, in a more recent investigation, Bonin, Peereman, and Fayol (2001) showed that, at least in written picture naming, the assembled phonology (Phoneme-Grapheme-Conversion, PGC) influences graphemic encoding. These results suggest that the orthographic system does indeed represent an independent module, which *can* benefit from computations of other components of the language processing system, but which *is* capable of processing linguistic information without support from the phonological component.

To summarise, two fundamental aspects of written language have been evidenced in the literature: First, written language shows a syllable-like hierarchical organisation; second, graphemic representations are largely independent of spoken language.

Phonological awareness and written language in the deaf

Until recently, research on the hypothesis of orthographic autonomy has paid less attention to deaf individuals than to dysgraphics. If the presence of orthosyllables is guided by phonological structures that develop through the auditory experience of spoken language then graphemic structures in the prelingually and profoundly deaf will *differ* from those in individuals with normal hearing.

Although, the acquisition of phonological representations can have multiple sources. The main sources, exclusively available for the hearing, are the numerous and precise auditory language inputs, partially percieved even before birth (e.g., Mehler, et al., 1988). Although people suffering from profound hearing loss do not have direct access to acoustic characteristics of spoken language, they can benefit from other visual and gestural sources like speech-reading, Cued Speech, speech articulation, or other sources (like bone conduction) to build up phonological representations. The results reviewed in Sterne and Goswami (2000) point to two aspects influencing the acquisition of phonology in the hearing-impaired: First, phonological skills are influenced by the level and/or the method of education. Well developed phonological skills seem to be restricted to highly educated individuals (Hanson, 1986; Hanson & McGarr, 1989) and also to children trained in Cued Speech from an early age (Charlier & Leybaert, 2000; Leybaert, 2000). Speech intelligibility alone does not seem to provide a reliable measurement for phonological skills (Charlier & Leybaert, 2000; Hanson, 1986; Hanson & Fowler, 1987; Hanson & McGarr, 1989; Waters & Doehring, 1990; but Transler, Gombert, & Leybaert, 2001). In general, phonological representations in the hearing-impaired are primarily dependant on the quality of the linguistic input and on the age of acquisition.

Second, the amount of phonological awareness seems to vary at different phonological levels: Sterne & Goswami (2000) found congenitally and profoundly deaf children to show syllable awareness which is equivalent to that of chronological age-matched hearing controls in a syllable counting task, but they display poorer rime judgements and phonemic skills. Evidence for a comparable use of syllabic templates in a segmentation/copying task by deaf and hearing children has been put forward by Transler, Leybaert, and Gombert (1999). In rime judgement tasks, hearing-impaired children and students who are educated orally or with sign language seem to rely more on their spelling knowledge (Campbell & Wright, 1988) and can be misled by speechreading similarities (Charlier & Leybaert, 2000; Sterne & Goswami, 2000). Detailed phonological knowledge in terms of distinctive features might not be available to the same extent as in the hearing because deaf individuals, at least those not exposed to Cued Speech, may not obtain enough cues to discriminate phonemes. However, suprasegmental phonological features, which are less dependent on the perception or production of accurate phonological contrasts, might be well developed in the hearing-impaired.

Another question is how phonological skills are related to reading and spelling (and fingerspelling). Although orthographic information is widely accepted to support the development of phonological awareness, studies show that skilled reading ability alone does not lead to the detailed and accurate phonological representations necessary for rime manipulation (Hanson and Fowler, 1987; Hanson & McGarr, 1989). As hearing and hearing-impaired children, who were matched in terms of their reading level, differed in the awareness of rimes and phonemes, Sterne and Goswami (2000, p. 621) argue that "orthographic learning does not govern the development of phonological awareness in deaf children". Similarly, hearing and hearing-impaired children, who were matched in terms of their spelling level (the latter being older and exposed to print for a longer time), did not differ on aspects indicative of the development of orthographic representations (Leybaert, 2000).

Effects of syllabic structure during reading in the deaf have been reported by Olson and Nickerson (2001). Although the effect was not as large as in hearing students (Rapp, 1992), the errors of deaf students in a judgement and segmentation task clearly indicated that they organised orthographic strings into syllables. The effect was not correlated to speech production or speech comprehension scores. Furthermore, bigram frequencies (i.e. the frequency of occurrence of two adjacent letters) were a less accurate measure than syllable boundaries in Olson and Nickerson's (2001) data. Their results were confirmed by the spelling errors of deaf individuals (Olson & Caramazza, 2004). Although the general error pattern differed from a hearing control group (the deaf made substantially less phonologically plausible errors), the great majority of errors were orthographically legal. Again, frequency measurements failed to explain the data. The authors concluded that the orthosyllable is a better concept than the statistical co-occurrence of letters because the errors respected larger contextual information and letters were not substituted by more frequent letter combinations. Following these conclusions, one might argue that the syllable represents an abstract linguistic unit, which can be acquired independently of the auditory experience of spoken language. These abstract principles govern the organisation of linguistic knowledge and apply to both spoken and written language.

Syllabic structures in typing

Almost all data reported so far were obtained ‘offline’, i.e. without any information on the time course during production. Therefore, it is of great interest to compare whether results based on ‘online’ timing measurements also support the notion of abstract syllables in written language. Although several authors have hinted at the influence of syllables on the time course of typing (Gentner, Larochelle, & Grudin, 1988; Ostry, 1983; Shaffer, 1978), none of these studies have promoted the view of syllables as processing units in typing. Zesiger, Orliguet, Boë, and Monoud (1994) found increased interkey intervals (IKIs, i.e. the time between two successive keystrokes) at within-word syllable boundaries in typewriting. These results were substantiated by recent experiments undertaken by Nottbusch, Weingarten, and Will (1998) and Weingarten, Nottbusch, and Will (2004), applying the analysis of discontinuous typing (Gentner et al., 1988; Shaffer, 1978; Sternberg, Monsell, Knoll, & Wright, 1978; Terzuolo & Viviani, 1980). The authors investigated the time course of word-typing in adults and found significant delays at within-word syllable onsets (in terms of the “start” of a within-word syllable). Furthermore, typing with and without suppressed subvocal articulation (by singing a constant tone) did not affect the overall timing pattern indicating that the syllabic organisation of the graphemic output is independent of any articulatory processes accompanying the typing.

The present study explored the impact of spoken language on the syllabic structure in typing. Comparing the time course of typing of deaf individuals with that of hearing persons, we investigated whether the syllabic structure is dependent on experience with spoken language. If syllables in writing are directly linked to the auditory experience of spoken language, we expected deaf individuals to differ from the hearing controls in the overall pattern of graphemic organisation. If, in contrast, syllables in writing do not depend on spoken language experience, no differences would be expected.

Two experiments with deaf individuals and hearing controls were conducted. In Experiment 1, deaf and hearing participants performed a written picture naming task to test whether the groups differ with respect to the syllabic pattern in the typing of real words. The experimental design allowed for a direct comparison of IKIs at different linguistic within-word boundaries. Due to the two groups' different experiences with spoken language, similar patterns of performance for the two groups would suggest that the effect must not be one based on spoken language. Instead, identical syllabic effects must have their origin in abstract principles of organisation, as postulated by the hypothesis of orthographic autonomy (Badecker, 1996; Olson & Caramazza, 2004; Olson & Nickerson, 2001).

A second question addressed by the experiments is the source of the syllabic units, or more precisely: Are the syllabic structures appearing in the time course of typing generated lexically or post-lexically? Effects of word properties, word frequency (Jescheniak & Levelt, 1994) or age of acquisition (Ellis, Morrison, & Quinlan, 1992), for example, are often taken as evidence for the involvement of lexical processes. Word frequency effects on the time course of typing have been shown to appear not only word initial, but also during production. Indeed, word frequency has been shown to affect the duration of IKIs *only* at combined morpheme and syllable boundaries in complex word forms but *not* at 'pure' syllable boundaries or other bigrams (Weingarten et al., 2004; but see Gentner et al., 1988, for a very small [<10 ms] effect). The absence of an effect at pure syllable boundaries, of course, does not exclude lexical involvement, but hints towards post-lexical processes. Concerning possible differences in the performance of hearing-impaired and hearing participants, Pinto, Monsalve, Cuetos and Rodriguez-Ferreiro (2004) found age of acqusition and word frequency effects of comparable size in error patterns. With regard to the results from Pinto et al. (2004), we expected effects of word frequency on the time course of typing to be similar in both groups.

The question of the origin of the syllabic units was further addressed in Experiment 2: If the graphemic syllabification is indeed caused by abstract principles rather than lexical information, we would also expect it to appear in pseudowords. An effect of increased interkey intervals at syllable boundaries in pseudowords, which have no direct orthographic or phonological real word neighbours, would imply an extra-lexical source of syllabification. Therefore, we asked deaf and hearing participants to type pseudowords.

Experiment 1: type-written picture naming in deaf and hearing participants

The time course of typing words has been shown to be influenced by the involvement of linguistic processes in written language production. Units like morphemes, syllables and graphemes lead to IKIs on different hierarchical levels: As within-syllable IKIs are shorter than IKIs for (identical) bigrams straddling a syllable boundary, graphemes are assumed to represent units of a lower hierarchical order than syllables. The longest within-word delays were measured when bigrams straddled a root morpheme boundary, also being a syllable boundary by default in German. Only the latter type of boundary has been shown to be affected by word frequency, indicating that lexical processes are active at this hierarchical level but not at the syllable or grapheme level (Weingarten et al., 2004).

Concerning the aim of this study, the differences between within-syllable IKIs and between-syllable IKIs is of great interest. If the increased IKIs at syllable boundaries in written production are based on abstract principles (that can be acquired independently of the auditory experience of spoken language), we expected the prelingually and profoundly deaf participants to show the same timing patterns as hearing adults in a direct comparison of the subword linguistic boundaries. In other words, we expected to find significant differences between the IKIs for bigrams involving a syllable boundary compared to (identical) bigrams with 'simple' letter transitions in both groups. If the deaf and the hearing participants rely on the same mechanisms, there should be no differences in the general pattern of behaviour. In addition, equivalent mechanisms should show equal patterns concerning the involvement of lexical processes.

Method

Design

The time course of typing is influenced by a number of non-linguistic factors (Rumelhart & Norman, 1982; Sternberg et al., 1978).

According to Gentner (1983), the strongest influence on IKIs (or in other words: the time span before a key press) is exerted by the immediately preceding character (reduction of variability of the IKIs [interquartile range] by about 43%). Tri-graphs and higher level n-graphs seem to contribute very little to the timing of keystrokes (Larochelle, 1983; for a detailed discussion see Weingarten et al., 2004). Based on these results, we conclude that it is both necessary and sufficient to compare only *identical bigrams* (bigram = two adjacent characters). Our basic assumption is that a fluent typist will, in all likelihood, type identical bigrams in the same motor pattern, i.e. each key with the same finger, independent of the learned typing system (touch-typing vs. two-finger-typing).

Crucial to our study is the fact that most bigrams can occur in more than one kind of location within a word in alphabetic writing systems. Consider for example the bigram ⟨is⟩ in the German words ⟨Maiskolben⟩ [corn cob], ⟨Kreisel⟩ [top], and ⟨Bleistift⟩ [pencil]:

- ⟨is⟩ in ⟨M a **i s** k o l b e n⟩ is a within-syllable bigram (henceforth, IKIs associated to 'simple' letter boundaries are called L-IKIs)
- ⟨is⟩ in ⟨K r e **i s** e l⟩ is a between-syllable bigram (⟨is⟩ straddles a syllable boundary; henceforth, IKIs associated to syllable boundaries are called S-IKIs)
- ⟨is⟩ in ⟨B l e **i s** t i f t⟩ is a between-syllable bigram that additionally straddles a morpheme boundary (henceforth, IKIs associated to syllable and morpheme boundaries are called SM-IKIs)

Based on the assumptions mentioned above, the IKIs for ⟨is⟩ (the times between the strokes of the ⟨i⟩-key and the ⟨s⟩-key) in ⟨Maiskolben⟩, ⟨Kreisel⟩, and ⟨Bleistift⟩ can be compared independent of influences from non-linguistic factors, for example the spatial order of the keys on the keyboard, a motoric advantage for frequent letter sequences, linguistic factors like bigram frequencies or other context effects. The only remaining factor is the type of linguistic boundary between the two characters of the bigram.

The activation of phonological representations seems to be influenced by the response mode (see Sterne & Goswami, 2000, p. 610; Transler et al., 2001, p. 62). In this respect, it is important to note that written picture naming does not include an oral response. In addition, pictures of objects do not involve any phonological or orthographical information of the stimulus. Therefore, written picture naming requires lexical semantic activation to obtain the information necessary for writing. Obligatory activation of phonological representations is not induced by the task.

Participants

Twenty deaf individuals participated in the experiment (16 from a local self-help centre in Osnabrück, Germany (a private association of hearing-impaired individuals, holding regular meetings, providing courses, lectures and advisory services), and four undergraduates from the University of Frankfurt [M.]; 14 female, 6 male). Eighteen of the deaf participants had complete hearing loss from birth, whilst the remaining two lost all hearing abilities at the age of 5 and 15 months respectively. They can therefore be considered as being prelingually deaf (audiological category according to the participant's statements: profound deafness, measurements of pure tone receptivity were not available; cf. Marschark, 1993, p. 14). All but three have hearing parents; two have a deaf father and the parents of one participant are both deaf. Twelve of the deaf participants learned German sign languages (DGS) before the age of six. Seven of these also learned LBG [Lautsprach-Begleitende Gebärden (gestures accompanying overt speech)], which is actually not considered to be a sign language (no independent grammar). The remaining eight deaf individuals learned signing around adolescence. In most German special schools for the deaf, the education is mainly focussed on overt speech, which was the case for all of the deaf participants of this study. Although speech and reading abilities were not collated, we can note that speaking abilities varied widely from 'uses speech and is fairly easily understood' to 'does not use speech as long as not forced to'. In a comparable study, Olson and Nickerson (2001) found no correlation between the strength of syllable effects in a reading/segmentation task and residual speech or hearing. The deaf individuals were all aged between 20 and 60 (Mean: 30.7, SD: 10.3) and all were either engaged in regular employment or were taking part in vocational training.

The hearing group consisted of 20 (16 female and 4 male) native speakers of German (undergraduates from the University of Osnabrück, Germany) who were between 21 and 30 years of age (Mean: 24.6, SD: 2.8). All participants were able to type fluently without hesitation, although no strict criterion was applied to the typing speed.

Stimuli

The complete set of 260 pictures from Snodgrass and Vanderwart (1980) was scanned for German picture names containing bigrams which occur at at least two different within-word boundaries. Ninety-two black-and-white line drawings of objects which conformed to the experimental requirements were selected: The German names contained at least one bigram found at a different boundary type in another word.

For example, the bigram ⟨et⟩ is found as a 'simple' letter boundary (L-type) in the word ⟨B **e t** t⟩ [bed], in the word ⟨T r o m p **e t** e⟩ [trumpet] there is a syllable boundary (S-type) between ⟨e⟩ and ⟨t⟩, and, in the word ⟨K a f f e **e t** a s s e⟩ [coffee cup], a combined syllable and morpheme boundary (SM-type) is found. Note, that not all bigrams used for the analysis appear in all of the three categories.

Apparatus

The experiment was conducted using a standard PC with a USB-keyboard (chosen because of its high sampling rate) and a 19″-CRT display. Stimulus display and keystroke measurements were controlled by Exp-Kit, a program designed to record keyboard data with maximal sampling rate in psycholinguistic experiments written by Boris Gutbrod. By using this equipment we were able to achieve an accuracy of approximately 8 ms.

Procedure

General information and instructions for the 16 deaf individuals from Osnabrück were signed during a first meeting. Detailed instructions were given in written form before testing. Instructions for the four deaf participants from Frankfurt (M.) were the same and were signed completely. The hearing participants received the same written instructions as the deaf groups.

In order to enhance the number of identical answers for the same picture, the whole set of pictures was presented to the participants twice in a random order during a preliminary phase. As comparable responses in picture naming do not occur as a matter of course, 'specified elicitation' methods (cf. Bonin et al., 2001) are widely used. The environment for this training was identical to the actual experiment. Each trial started with the display of an empty frame (300×400 pixel on a 19″ screen with 1024×768 pixel resolution) in the upper half of the screen for 1000 ms. This was followed by the presentation of a fixation mark in the middle for 50 ms. Following a blank screen of 200 ms, the picture was presented. Participants were first asked to name the picture in their minds and then to press the return key in order to read the intended word presented in the lower half of the screen. The mental naming prior to reading was implemented to evoke active processing of the stimulus. The next trial was initiated self paced and started 1500 ms after pressing the return key.

After the training phase, 10 pre-test pictures (not contained in the main list) were presented in almost the same fashion as above. Here, participants were asked to type the name of the picture as quickly as possible, without errors. The picture disappeared at the same time as the first character was typed. Characters typed became visible on the lower half of the screen and could be corrected in case of mistyping just as with any normal word processor. Following the pre-test and, if necessary, repeated instructions the main test was conducted. IKIs were measured.

Results

Six stimulus-words were discarded from the analysis of IKIs because more than 50% of one group of participants gave an incorrect answer (see Appendix A). The following analyses are based on correct responses to the remaining 86 pictures (word initial latencies were not considered). Including the errors from the six discarded stimuli, 21.2% of the words typed (deaf: 24.0%; hearing: 18.3%) were excluded because of mistyping, zero reaction or incorrect naming. After a visual inspection of the histograms, IKIs exceeding 3000 ms (16 data (deaf: 15; hearing: 1), corresponding to 0.09% of the dataset) were excluded in order to equalise standard deviations. With the remaining IKIs, all values exceeding 2.5 standard deviations of the participants mean IKI (2.7% of the data (deaf: 2.9%; hearing: 2.6%)) were regarded as outliers and therefore not considered in the analyses.

All bigrams that are immediately adjacent to an ambiguous syllable onset were excluded from the analyses. This is the case if a written geminate denotes an ambisyllabic consonant as in ⟨Karo-t-te⟩ [carrot], in the bigram ⟨st⟩ (e.g., in ⟨Pi-s-tole⟩ [pistol]) and in one case ⟨br⟩ in ⟨Ze-b-ra⟩. In all of the cases mentioned the German phonotactical determination of the syllable onset (onset maximisation) and the graphotactical one (one-grapheme-rule) differ (cf. Eisenberg, 1998, p. 295).

The remaining 86 words contained 47 bigrams that conformed to the experimental requirements by occurring in at least two of the three kinds of location within a word. The analyses had to be divided into three because only identical bigrams can be reasonably compared and also because bigrams straddling all three types of boundaries were rare due to language constraints. Twentynine different bigrams appeared at 'simple' letter boundaries (L-type) in one of the target words *and* at syllable boundaries (S-type) in another word and were therefore used in the L vs. S condition. Eleven bigrams appeared both as L-type *and* at locations straddling a syllable and morpheme boundary (SM-type) and were analysed in the L vs. SM condition. The analysis of the S vs. SM condition is based on the results of six bigrams that occurred as S-type *and* SM-type.

The focus of interest is on the influence of the factors ‘type of boundary’ and ‘status of hearing’. Therefore, both were introduced as fixed factors in a mixed model. The mean duration of IKIs for different bigrams varies to some degree. In addition, the actual bigrams and their number for each type of boundary is random and not equal due to language constraints. Therefore, bigrams were inserted as a random factor in the mixed model. Due to the fact that variation in typing speed between and within groups was considerably high (deaf: 103 to 483 keys/min. (Mean: 233.4; SD: 79.7); hearing: 156 to 424 keys/min. (Mean: 304.5; SD: 69.2)), individual differences were used as a second random factor. Both random factors were assumed to be normally distributed.

Letter (L) vs. Syllable (S) boundaries

For the comparison of L vs. S boundaries 4164 single measurements (L = 2889, S = 1275; deaf = 2018, hearing = 2146) were considered. The following 29 bigrams were used: ⟨ah⟩, ⟨al⟩, ⟨am⟩, ⟨an⟩, ⟨ar⟩, ⟨as⟩, ⟨at⟩, ⟨ef⟩, ⟨el⟩, ⟨en⟩, ⟨er⟩, ⟨et⟩, ⟨hl⟩, ⟨hn⟩, ⟨ib⟩, ⟨if⟩, ⟨in⟩, ⟨is⟩, ⟨lb⟩, ⟨nt⟩, ⟨ol⟩, ⟨om⟩, ⟨on⟩, ⟨or⟩, ⟨ot⟩, ⟨rg⟩, ⟨rn⟩, ⟨ub⟩, ⟨ug⟩. As mentioned above, all bigrams appear at least once as L-IKI *and* as S-IKI in one of the target words.

Within the deaf group, S-IKIs were typed on average 72 ms slower (Mean: 388 ms, SD: 277) than the L-IKIs (Mean: 316 ms, SD: 232). The difference between S-IKI and L-IKI within the hearing group was 38 ms (S: Mean: 261 ms, SD: 140; L: Mean: 223 ms, SD: 129; see Figure 1).

A mixed model ANOVA showed significant effects for the fixed factors type of boundary, $F(1, 4120.4) = 31.1$, $P < 0.001$ and status of hearing, $F(1, 37.9) = 10.1$, $P < 0.01$. The interaction between both factors was also significant, $F(1, 4097.9) = 20.3$, $P < 0.001$, which is due to a larger effect for deaf than for hearing participants. The standard deviation for the random factor bigram was 49.0 (SE: 7.0) and 135.5 (SE: 15.7) for the random factor participants. Besides individual differences in typing speed, S-IKIs were typed slower than L-IKIs by 19 out of 20 participants in both groups.

Letter (L) vs. Syllable/Morpheme (SM) boundaries

Comparison of L and SM boundaries was done by taking the following eleven bigrams (occurring at least once in L-IKIs and SM-IKIs): ⟨em⟩, ⟨et⟩, ⟨is⟩, ⟨lb⟩, ⟨le⟩, ⟨ls⟩, ⟨ng⟩, ⟨ns⟩, ⟨nt⟩, ⟨rg⟩, ⟨rm⟩ into account. The

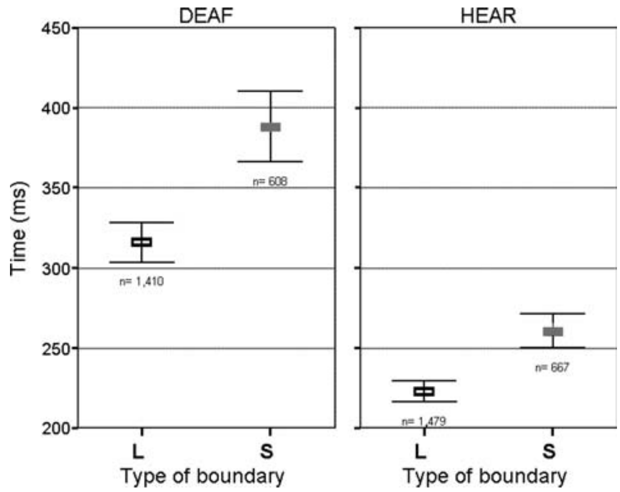

Figure 1. Means and error bars (95% confidence interval) for IKIs at within-syllable bigrams (L-type) and between-syllable bigrams (S-type) for deaf (DEAF) and hearing (HEAR) participants in a typed picture naming task.

analysis is based on 1057 single data (L: 676, SM: 381; deaf: 524, hearing: 533). SM-IKIs were considerably delayed in both groups compared with the L-IKIs occurring at the same bigrams. For the deaf typists the difference amounted to 156 ms (L-IKIs: Mean: 334 ms, SD: 225; SM-IKIs: Mean: 490 ms, SD: 320) and hearing typists showed a difference of almost exactly 100 ms (L-IKIs: Mean: 215 ms, SD: 130; SM-IKIs: Mean: 315 ms, SD: 162; see Figure 2). A mixed model ANOVA (analogous to the L vs. S condition) revealed significant effects for the fixed factors type of boundary, $F(1, 1002.9) = 136.9$, $P < 0.001$ and status of hearing, $F(1, 37.6) = 13.1$, $P < 0.01$. The interaction between both factors was also significant, $F(1, 1005.8) = 8.8$, $P < 0.01$, which is again due to a larger effect for deaf than for hearing participants. The standard deviation for the random factor bigram was 42.5 (SE: 11.1) and 154.2 (SE: 18.6) for the random factor participants. The SM-IKIs were typed slower than the corresponding L-IKIs by all deaf individuals and by 18 of the 20 hearing participants. (Note: differences between the L-IKIs described above [L vs. S] and here [L vs. SM] are due to different sets of bigrams.)

Syllable (S) vs. syllable/morpheme (SM) boundaries

Finally, S boundaries were compared with SM boundaries for the six bigrams ⟨et⟩, ⟨is⟩, ⟨lb⟩, ⟨nt⟩, ⟨rf⟩, ⟨rg⟩ (all occurring as S-IKIs and SM-IKIs

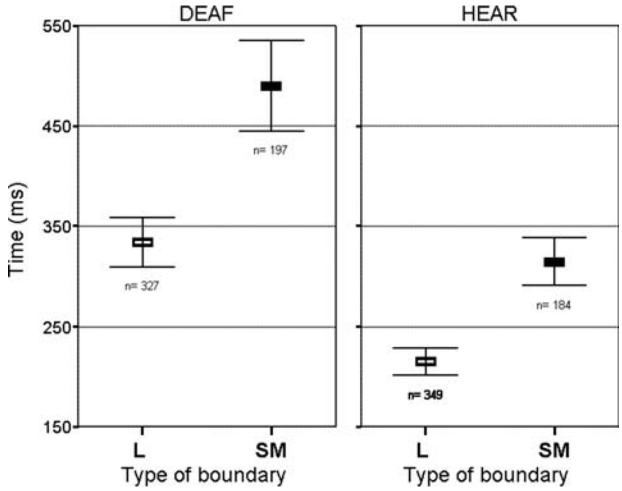

Figure 2. Means and error bars (95% confidence interval) for IKIs at within-syllable bigrams (L-type) and between-syllable and morpheme bigrams (SM-type) for deaf (DEAF) and hearing (HEAR) participants in a typed picture naming task.

at least once). The analysis is based on 378 single measurements (S: 225, SM: 153; deaf: 177, hearing: 201). Two deaf participants were excluded from the analysis because they produced errors in all words containing the SM-IKIs. In the deaf group, SM-IKIs clearly took more time (Mean: 498 ms, SD: 336) than S-IKIs (Mean: 391 ms, SD: 342). The same pattern was obtained for the hearing group (SM-IKIs: Mean: 328 ms, SD: 159; S-IKIs: Mean: 243 ms, SD: 131; see Figure 3). Despite the comparably low number of items, the difference between the two boundary types was significant, $F(1, 334.3) = 31.7$, $P < 0.001$. The effect of status of hearing again was significant, $F(1, 35.1) = 6.4$, $P < 0.05$ but not the interaction between the two factors, $F(1, 334.1) = 1.2$, $P > 0.1$. The standard deviation for the random factor bigram was 44.1 (SE: 16.3) and 232.7. (SE: 29.1) for the random factor participants. Seventeen out of 18 deaf participants and 16 out of 20 hearing participants showed longer durations initiating a root morpheme/syllable segment (SM-IKI) than a 'simple' syllable (S-IKI). (Note: differences between the S and SM-IKIs described above [L vs. S; L vs. SM] and here [S vs. SM] are due to different sets of bigrams.)

Word frequency effects

In order to test for word frequency effects within the S-IKIs and the SM-IKIs, the stimulus words were labelled as either high or low

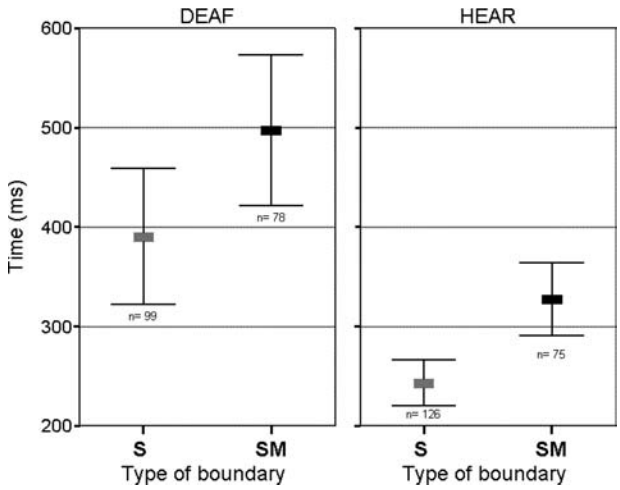

Figure 3. Means and error bars (95% confidence interval) for IKIs at between-syllable bigrams (S-type) and between-syllable and morpheme bigrams (SM-type) for deaf (DEAF) and hearing (HEAR) participants in a typed picture naming task.

frequency items by retrieving their log normal frequency from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993; items not contained in CELEX or having an absolute frequency of zero were assessed with a log value of zero). The borderline between high and low frequency items was set to 2.5 for both analyses (corresponding to an absolute frequency of 12.18 per 5.4 million words from the Mannheim corpus of written texts contained in CELEX). As the number of items with identical bigrams occurring as high and as low frequency was too low, all S-IKIs and SM-IKIs were considered for the analyses.

For the comparison of S-IKIs contained in either high frequency or low frequency words, 2709 single measurements (high = 1350, low = 1359; deaf = 1286, hearing = 1423) were taken into account. High frequency words had a mean log normal frequency of 4.44 (SD: 1.14) and low frequency words had a mean log normal frequency of 0.96 (SD: 0.92). Within the deaf group, S-IKIs in high frequency words were typed at almost the same speed (high frequency: Mean: 373 ms, SD: 366; low frequency: Mean: 374 ms, SD: 319). The difference between high and low frequency S-IKIs within the hearing group was also only very slight (high frequency: Mean: 256 ms, SD: 192; low frequency: Mean: 264 ms, SD: 184). Therefore, it is not surprising that the mixed model ANOVA did not show a significant effect for the fixed factor word frequency, $F(1, 1645.2) = 1.1$, $P > 0.1$, but did show one for the status of hearing, $F(1, 37.4) = 8.5$, $P < 0.01$, indicating differences in typing speed. The interaction between both factors was not significant, $F(1, 2621.1) < 1$. The standard deviation for the random factor bigram was 91.7 (SE: 9.8) and 153.2 (SE: 18.3) for the random factor participants. These results were reflected in the fact that almost equal number of participants typed S-IKI in high frequency words faster than in low frequency words and vice versa (deaf: 9 to 11; hearing: 8 to 12). For the majority of participants, the differences were very slight.

The analysis of SM-IKIs occurring in high vs. low frequency words is based on 961 data (high = 236, low = 725; deaf = 474, hearing = 487). High frequency words had a mean log normal frequency of 3.96 (SD: 0.89) and low frequency words had a mean log normal frequency of 0.64 (SD: 0.82). In the deaf group, SM-IKIs in low frequency words took 103 ms longer (rounded; Mean: 596 ms, SD: 414) than SM-IKIs in high frequency words (Mean: 494 ms, SD: 373). The same pattern was obtained from the hearing group; here the difference was 65 ms (high frequency: Mean: 397 ms, SD: 256; low frequency: Mean: 331 ms, SD: 186). The difference between the high and low frequency items was significant, $F(1, 72.5) = 9.1$, $P < 0.01$, as was the effect of status of hearing, $F(1, 38.1) = 8.3$, $P < 0.01$, and the interaction between the two fixed factors, $F(1, 897.2) = 4.2$, $P < 0.05$, which is again due to a larger effect for deaf than for hearing participants. The standard deviation for the random factor bigram was 63.2 (SE: 12.6) and 238.0. (SE: 29.0) for the random factor participants. Sixteen out of 20 deaf and 17 out of 20 hearing participants needed more time to initiate a new SM-unit in low frequency words than in high frequency words.

Discussion

The present experiment confirms that linguistic information influences the time course of typing of deaf as well as hearing participants. Both groups display significant delays at S-type and SM-type boundaries in comparison to L-type boundaries. The general pattern of performance is strikingly similar. The results indicate that the syllabic organisation of the graphemic output is not based on spoken language, or in other words, it is not dependent on phonology acquired on the basis of experience with spoken language. Although, results from a neurolinguistic case study (Sahel, Nottbusch, Blanken, & Weingarten, 2005) demonstrate that syllabic structures are based on postlexical phonological processes. Therefore, we consider the appearance of a syllabic organisation in written spelling of deaf participants as an indication of the abstract nature of the syllable, i.e. of an amodal representation of the syllable.

The significant effects of groups are most likely due to the fact that both groups differ with respect to age, age span, educational level and typing speed. In addition, the deaf group is heterogeneous regarding the aforementioned factors, whereas the hearing group is comparably homogeneous. Therefore, the significant effects of group (status of hearing) within the different analyses are not surprising. Interactions between the factor type of boundary (or word frequency, respectively) and the factor status of hearing might be explained by the finding that the differences between the parameter values are larger in slow typists (i.e. the majority of the deaf participants) than in fast typists (i.e. the majority of the hearing participants). In other words, the following relation seems to hold: the slower the typist – the larger the differences in the parameter values. This view is supported by analyses using log normal transformed measurements that led to smaller (although still significant) effects concerning the interactions. The other fixed factors were almost unaffected by the transformation.

The production of words containing SM-IKIs (root morpheme boundaries that always fall together with syllable boundaries in German) seems to require lexical processes as indicated by the significant effect of word frequency on the related values. Again, the performance of both groups is strikingly similar, corroborating the results of Pinto et al. (2004). The timing of S-IKIs (IKIs for bigrams straddling a syllable boundary) on the other hand was *not* affected by word frequency in both groups. We take this finding as hinting towards sublexical syllabification, although lexical involvement can not be ruled out by a non-effect.

The fact that deaf and hearing participants do not differ with respect to the organisation of their type-written output indicates that spoken language experience plays a minor role in the time pattern of typing. In other words, if spoken language phonology would be the main factor for the timing structures, we would expect clear differences between the two groups. This is not the case. An emerging question is now whether the time pattern has a lexical or a non-lexical source. If the assignment of syllabic structure is a post-lexical process, as assumed in current models of graphemic representation (Caramazza & Miceli, 1990; McCloskey et al., 1994), non-lexical items, like pseudowords (without direct orthographic or phonological real word neighbours), would also be predicted to show a syllabic pattern. In order to test this prediction, deaf and hearing people were asked to type pseudowords in the following experiment.

Experiment 2: typing of visually presented pseudowords in deaf and hearing participants

The analysis of typing of real words is not sufficient to decide whether orthosyllables are generated at a lexical or at a post-lexical level. To obtain clearer evidence on the origin of the syllabic structure, we tested whether the deaf and the hearing participants also produced syllable-like patterns in pseudowords. If the syllabic pattern is indeed generated post-lexically, it should also appear in pseudowords that have, by definition, no lexical entry. Nevertheless, lexical activation is also possible during the production of pseudowords by accessing existing entries that are phonological or orthographic neighbours of the pseudoword. We tried to minimise the possible writing-by-analogy effects by using pseudowords that were manipulated to have no direct lexical neighbours.

A set of pseudowords containing bigrams straddling L-type as well as S-type boundaries was generated. By comparing IKIs for identical bigrams but different types of linguistic boundaries, the influence of the boundary type should remain the main factor.

Method

Design

The following experiment was conducted using the same experimental paradigm as in the previous experiment.

Participants

The deaf group consisted of 18 participants from the group described in Experiment 1 (due to human error, data from the two missing participants were not recorded). The participants of the hearing group were the same as in Experiment 1.

Stimuli

The material consisted of 16 phonotactically and graphotactically legal pseudowords whose lengths ranged from 5 to 13 letters. The number of syllables ranged from 2 to 4 (see Appendix B). All pseudowords were built by altering existing words by at least one consonant and the vowel in each syllable. The resulting pseudowords were again checked for phonologic and orthographic neighbours.

Apparatus

The technical equipment used was the same as in Experiment 1.

Procedure
General information and instructions were given to the participants as in Experiment 1. The pseudowords were presented visually in a randomised fashion. The position of the stimulus was indicated by an asterisk being displayed for 800 ms in the upper part of the screen. Following 200 ms of a blank screen, the pseudoword stimulus appeared. Stimulus exposure was self paced by pressing the return key before typing, i.e. the stimulus disappeared simultaneously with the first keystroke. The next trial was initiated self paced and started 1500 ms after pressing the return key. As in Experiment 1 the characters typed appeared (and were editable) in the lower half of the screen. The participants were instructed to read the pseudowords and to type them as quickly as possible without errors. After a training phase, including 12 stimuli (not contained in the main list) and, if necessary, repeated instructions, the main test was performed.

Results

Mistyped words and zero reactions (21.7%; deaf: 29.9%; hearing: 14.4%) were discarded from the analysis of the IKIs. During a visual inspection of the histograms of the remaining IKIs no obvious distractions (i.e. IKIs exceeding 3000 ms) were found. As in Experiment 1, values exceeding 2.5 standard deviations of the participants mean were considered as outliers (DEAF: 2.6% of the data; HEAR: 2.7%).

The analysis was performed using the same mixed model ANOVA as in Experiment 1: the factors 'type of boundary' and 'status of hearing' were used as fixed factors and the factors bigram and individual differences were inserted as a random factor. Both random factors were assumed to be normally distributed. As in Experiment 1, we found a large variability in typing speed between and within groups (deaf, Mean: 169.9 keys/min., SD 60.8: ranging from 68 to 299; hearing, Mean: 238.3 keys/min., SD 49.7: ranging from 140 to 316). Both groups performed slower in comparison to the preceding experiment.

The following analysis is based on the set of eight bigrams occurring both at syllable boundaries *and* in within-syllable positions in the pseudoword stimuli: ⟨al⟩, ⟨an⟩, ⟨el⟩, ⟨en⟩, ⟨ok⟩, ⟨on⟩, ⟨st⟩, ⟨ur⟩. 660 single measurements (L = 233, S = 427; deaf = 280, hearing = 380) were taken into account for the comparison of L vs. S-IKIs.

As in Experiment 1, the deaf and the hearing participants showed similar patterns of keystroke timing. The deaf participants typed the within-syllable IKIs 38 ms faster compared to between-syllable boundaries (L-IKIs: Mean: 310, SD: 227; S-IKIs: Mean: 348, SD: 242). The hearing participants needed 34 ms less for within-syllable IKIs than for between-syllable IKIs (L-IKIs: Mean: 221, SD: 116; S-IKIs: Mean: 255, SD: 156, see Figure 4).

Despite the comparably low number of cases, a mixed model ANOVA showed significant effects for the fixed factors type of boundary, $F(1, 612.8) = 12.2$, $P = 0.001$, and status of hearing, $F(1, 30.0) = 10.4$, $P < 0.005$, but no significant interaction between the factors, $F(1, 607.3) < 1$. The standard deviation for the random factor bigram was 48.3 (SE: 15.0) and 101.5 (SE: 15.4) for the random factor participants. S-IKIs were typed slower than L-IKIs by 15 out of 18 deaf participants and 17 out of 20 hearing participants.

Discussion

The written responses of both, deaf and hearing, groups showed significant delays at syllable boundaries. As in the typing of real words, S-type IKIs are significantly delayed in comparison to L-type IKIs in controlled bigram contexts. We interpret this pattern as an indication for a syllabification process in typing pseudowords.

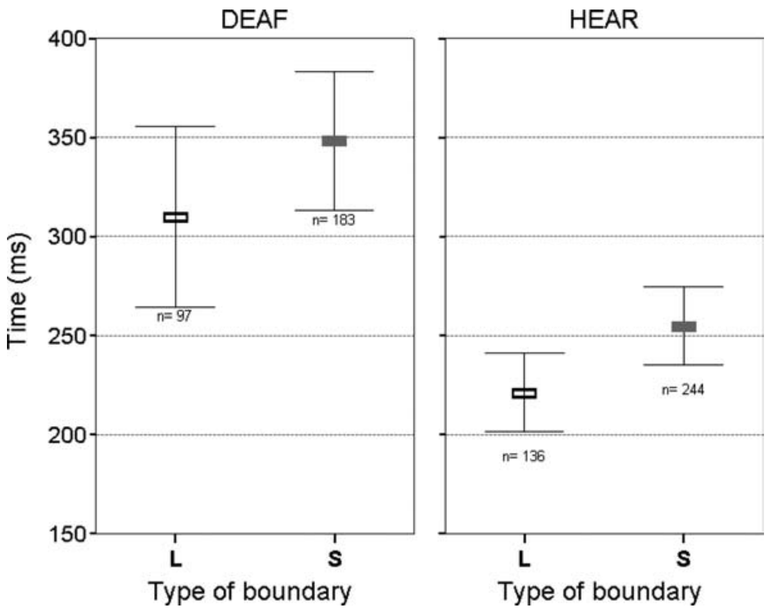

Figure 4. Means and error bars (95% confidence interval) for IKIs at within-syllable bigrams (L-type) and between-syllable bigrams (S-type) for deaf (DEAF) and hearing (HEAR) participants in a pseudoword typing task.

Both groups slowed their typing speed while writing pseudowords compared to written picture naming. Additionally, the deaf participants slipped more often whereas the hearing participants produced fewer errors in written picture naming. The latter difference may be due to different strategies for maintaining the stimulus. Although the deaf participants may be impoverished concerning (especially segmental) phonology, they must have some kind of rehearsal loop that is based either on visuospatial recoding (cf. Wilson & Emmorey, 1997), perhaps assisted by finger spelling (observed in three deaf participants), or articulation (Burden & Campbell, 1994). An articulatory-based phonological loop as the source of the orthosyllabic pattern is unlikely for the hearing participants (cf. Weingarten et al., 2004, described above) and implausible for deaf individuals who commonly avoid oral spelling if they can. Although an interesting point, we do not go into further detail here, since the precise relation between the rehearsal strategy used by participants and the orthosyllabic pattern is not the focus of the present study. Instead, we concentrated on syllables in typing and the locus of their generation. In agreement with current models, we assume this to be a post-lexical process. The occurrence of the syllabic pattern is unlikely to stem from the activation of existing words that are phonologic or orthographic neighbours of the pseudowords as this factor was controlled. This indicates that the timing pattern in the typing of pseudowords is due to a mechanism which applies independently of lexical information.

General discussion

Several characteristics in the performance of the deaf and the hearing group provide evidence that the graphemic representation in typing is organised into larger units. First, syllable onsets cause delayed IKIs in the time course of typing. Second, the delays are enhanced if syllable onsets are processed at the same time as morpheme onsets (SM-IKIs). Generally speaking, the present study demonstrated that deaf and hearing participants produce a largely similar time pattern in typing.

Interactions between the factors type of boundary and status of hearing in the comparison of within syllable (L) and between syllable (S) IKIs (as well as for the comparison of L-IKIs with SM-IKIs, and for the comparison of SM-IKIs occurring in high and low frequency word) in Experiment 1 seem to be largely due to the heterogeneity within the deaf group opposed to the relative homogeneity of the hearing group. In this context it is interesting to note, that there appears to be a connection between typing speed, variability and the size of the syllable effect. Analyses performed on the basis of log normal transformed measurements weakened the interaction, although the differences were still significant. We take this, and the fact that the concerned differences are *larger* in the deaf group compared to the hearing group, as indicators for the general pattern of performance and the underlying processes of syllabification and lexical access being the same in the deaf and the hearing participants.

It is unlikely that the significant effect of longer latencies at between-syllable IKIs compared to matched within-syllable IKIs are mediated by spoken language phonology since hearing-impaired individuals have impoverished phonological processing, particularly concerning segmental conversion (see Introduction). Furthermore, although hearing-impaired individuals in Germany, and our participants in particular, are frequently taught to speak overtly in German schools for the deaf, it is unlikely that our participants have built up phonological representations based on articulatory, sensory-motor or other feedback comparable to those achievable using Cued Speech (Charlier & Leybaert, 2000; Leybaert, 2000). Moreover, their speaking abilities varied widely. Therefore, it is improbable that the syllabic structures observed in the time course of typing arose from articulatory abilities. Since the deaf participants of our experiment are prelingually and profoundly deaf and were not trained in any special way, we can assume that they rank below average concerning phonological skills within the hearing-impaired community. In spite of their limited phonological skills, they showed a syllabic pattern in the time course of typing similar to hearing participants. In addition, although the group of deaf participants was rather heterogeneous (see above), the observed syllabic pattern is prevalent within the group (within-syllable IKIs were typed on average faster than matched between-syllable IKIs by 95% of the deaf participants). Hence, we argue that our results could be generalised for the hearing-impaired community as a whole and that the syllabic pattern is independent of phonological skills that develop through spoken language experience or visual and gestural sources.

Given that clear effects of syllabic units in typing have been found in deaf and hearing participants, it may be surprising to know that we are not dealing here with aspects of the internal structure of orthosyllables. The reason is that the design of our study is based on matched bigrams in different linguistic contexts, making it difficult to look for internal properties of the syllable like C/V status or letter doubling. Thus, with respect to the internal structure of the graphemic syllable, we refer to earlier evidence from error patterns, predominantly from neuropsychological single case studies (e.g., Caramazza & Miceli, 1990;

McCloskey et al., 1994; Ward & Romani, 2000). In this sense, the time based method provides complementary evidence to the error-based method: While we focus on syllabic information as a whole, qualitative approaches implicate the existence of orthosyllables indirectly from internal constraints on the syllable structure.

Various studies indicate that the graphemic syllable is largely independent of spoken language. Although under certain circumstances, the allocation of graphemic information is supported by phonology (Bonin et al., 2001), graphemic representations generally have their own principles of organisation (Caramazza & Miceli, 1990; McCloskey et al., 1994). Experiments on written language production provide a third source of evidence (besides spoken and sign language) to establish the concept of the syllable as an abstract and universal unit.

Another result to be discussed is the impact of lexical information on typing. In our data, both groups of participants showed the strongest delays at syllable onsets which coincide with a root morpheme onset. We interpret the longer, word-frequency-related, latencies at SM-IKIs as an indication of accessing the Graphemic Output Lexicon during typing. Since we only dealt with compounds in Experiment 1 of the present study, we have to be aware of generalisations about the impact of word formation on the time pattern. In contrast to compounds, suffixed forms are often re-syllabified in standard German leading to a mismatch between syllable and morpheme onset. Weingarten et al. (2004) report no effect of 'pure' morpheme onsets in the time structure in typing. Therefore, we are still undecided over the contexts in which the morphological information is 'overwritten' by syllabic information and how the time structure can be affected by affixation. Thus, the relationship between morphological and syllabic processing remains a point of further research (Nottbusch, Sahel, Grimm, & Weingarten, in preparation).

Our results match the psycholinguistic evidence provided by brain-damaged patients. English and Italian dysgraphics showed clear effects of syllable structure in writing in the absence of awareness of segmental and syllabic phonology in oral spelling (Caramazza & Miceli, 1990; McCloskey et al., 1994; Ward & Romani, 2000). Furthermore, as Domahs et al. (2001) showed for a German surface dysgraphic, syllabic information may influence the realisation of vowel length and consonantal allographs. Since surface dysgraphics have a very restricted access to lexical (output) information, the authors concluded that the syllabic structure must be provided by a non-lexical mechanism.

Three results of our study support current psycholinguistic models (see above) which assume syllabification to be a post-lexical process not stored in the lexical form. First, deaf and hearing participants produce a similar pattern in the typing of real words. Second, effects of word frequency are found at bigrams straddling both a syllable and a morpheme boundary, but not at pure syllable onsets. Third, the syllabic pattern also appeared in pseudowords, which do not have lexical entries.

One may wonder, however, about the apparent contradiction between our claim that the orthosyllable is represented post-lexically and, at the same time, that syllables are due to abstract principles. Syllables as abstract units should be mode-independent, while post-lexical processing of syllabic information is assumed to be mode-specific in written language. We understand the abstract nature of the syllable as a constraint that generally requires linguistic output to be parsed into syllables. Since syllabification varies between modalities and languages, the syllabification rules must be sensitive to the output. For instance, while syllables in spoken language favour onset maximisation (often resulting in complex onsets), orthographic syllables, at least in standard German, prefer simple onsets (cf. Eisenberg, 1998). With respect to sign language, the internal structure of syllables is more difficult to determine because the basic units are not segmental slots, but larger morphophonemic units. Further substantial differences are sonority requirements and the possibility to reduce unstressed syllables: In spoken language, sonorant consonants can be the nucleus. In contrast, in standard German orthography, graphemic syllables never allow nonvocalic nuclei.

One might argue that graphemic syllables constitute an unmarked subset of the syllabic repertoire of spoken language and that the seemingly inherent properties of graphemic syllables in fact reflect the derived nature of written language. If this were the case, we should not expect any differences between syllables in spoken and written language because graphemic units would simply reflect the phonemic units. Several empirical and theoretical reasons call into doubt the view that graphemic representations result from a unidirectional mapping of phonology to orthography (Primus, 2003).

Under these assumptions, the sources of the syllabic structure, evident in the typing of deaf individuals, is the abstract nature of the syllable that generally constrains the segmentation of linguistic output. This general knowledge of suprasegmental phonological features can be built up without precise auditory language inputs by using residual information about sounds coming from speech and/or lipreading and other visual and gestural sources like speechreading, or by information about the structure of words coming from reading and writing.

In the present study, we showed that linguistic units influence the dynamics of the typing process, independent of the experience of spoken language. Since effects of bigram frequencies (as well as other nonlinguistic factors) are ruled out due to our experimental design, the delays in the typing of deaf and hearing individuals correspond to

Appendix A

Stimuli for the written picture naming experiment (Experiment 2)

+ Ahornblatt [leaf]	Hemd [shirt]	Schmetterling [butterfly]
Ameise [ant]	Hose [pants]	Schneemann [snowman]
˜Arm [arm]	Hubschrauber [helicopter]	Schraubenschlüssel [wrench]
* Artischocke [artichoke]	+ Kaffeetasse [coffee cup]	* Schraubenzieher [screwdriver]
Auge [eye]	Kamm [comb]	Schreibtisch [desk]
Ball [ball]	+ Kaninchen [rabbit]	Seehund [seal]
Baseballschläger [baseball bat]	Kanone [cannon]	Segelboot [sailboat]
Berg [mountain]	Karotte [carrot]	Sonne [sun]
Besen [broom]	Koffer [suitcase]	Spargel [asparagus]
Bett [bed]	Kreisel [top]	* Stangensellerie [celery]
Biene [bee]	Krone [crown]	Stern [star]
Birne [pear]	Kugelschreiber [pen]	Telefon [telephone]
Bleistift [pencil]	Kühlschrank [refrigerator]	Tennisschläger [tennis racket]
¯ Brief [envelope]	Leiter [ladder]	Tomate [tomato]
Brille [glasses]	Lichtschalter [light switch]	+ Trillerpfeife [whistle]
Brot [bread]	Lineal [ruler]	Trommel [drum]
Elefant [elephant]	Maiskolben [corn cob]	Trompete [trumpet]
Esel [donkey]	Mantel [coat]	Türgriff [doorknob]
Fahne [flag]	Messer [knife]	+ * Vorhängeschloss [lock]
Fenster [window]	Motorrad [motorcycle]	Wäscheklammer [clothespin]
Flugzeug [airplane]	¯ Mülleimer [garbage can]	+ Wassermelone [watermelon]
˜ Gans [goose]	Nase [nose]	+ Weinglas [wineglass]
* Gießkanne [watering can]	Pfeife [pipe]	Weintrauben [grapes]

Appendix A Continued.

stimuli for the written picture naming experiment (Experiment 2)		
Gitarre [guitar]	Pistole [gun]	Windmühle [windmill]
Glas [glass]	˜ Querflöte [flute]	Wolke [cloud]
Gorilla [gorilla]	Ring [ring]	Zahnbürste [toothbrush]
Hahn [rooster]	Salat [lettuce]	Zebra [zebra]
+ Halbmond [half moon]	Schaukelstuhl [rocking chair]	* Ziehharmonika [accordion]
+ Halskette [necklace]	Schere [scissors]	Zigarette [cigarette]
Hand [hand]	˜ Schlitten [sled]	Zigarre [cigar]
Harfe [harp]	Schlüssel [key]	

Note: Items marked with a * were not written in a countable manner by more than 50% of the participants. A + denotes items being more complex in the actually form used than in the German norms by Genzel, Kerkhoff, and Scheffter (1995). Items that

Appendix B

Stimuli for the pseudoword experiment (Experiment 2)			
Aurelu	Fanumest	Naustan	Schmallerbing
Batonik	Graffriel	Nitretostar	Sokalier
Beotmang	Lanabe	Raftalon	Stellurt
Bostun	Miela	Ratenok	Tenumen

onsets of orthosyllables. Therefore, the results of our study provide additional support for the autonomy of graphemic representations.

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