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Valéria Csépe

*Research Centre for Natural Sciences, Brain Imaging Centre, Budapest*
*University of Pannonia, Institute of Hungarian and Applied Linguistics, Veszprém*
csepe.valeria@ttk.hu

# Interaction of phonology and orthography in spoken and spoken-sign language bilinguals

This review compares the core features of mono- and bimodal bilingualism, e.g. the use of spoken and sign language. Behavioral and brain correlates of the possible interactions of phonology and orthography in deaf people are discussed from the aspect of reading acquisition and development. The possible role of phonology in deaf children and its contribution to reading is discussed in relation to language proficiency, age, hearing status and bilingual balance. Corresponding as well as contradicting results of linguistic, psycholinguistic and neuroscientific investigations are discussed from the point of view of bimodal bilingualism.

## *Introduction*

The development of reading and writing in young children is primarily influenced by word-level skills including direct word recognition and spelling both depending on similar skills, e.g. phonological and orthographic processing. While phonological skills include procedural knowledge in service of reading, spelling is different in a sense as both phonological and orthographical skills contribute to its development on a distinct way as compared to reading. The phonological processing is assumed to enable spellers to segment the sounds in words and this contributes to reading acquisition in children. However, this approach corresponds to the traditional view on sound segmentation of words thought to be the prerequisite of reading. This view is in contradiction with the data published on several studies showing that access to sounds in words is the consequence and not the prerequisite of reading contrary to syllabic segmentation that emerges earlier than the phonological awareness on phonemic level (Vaessen et al, 2010; Blomert and Csépe, 2012).

As it was suggested by Gombert (1992, 1994) development of the phonological awareness undergoes two stages and can be assessed at two distinct levels: (1) epiphonological awareness and (2) metaphonological awareness. Unfortunately, this distinction is not used broadly enough in the literature although their relationship with reading development is rather different. While the epiphonological awareness refers to an implicit awareness of or sensitivity to the constituent sounds in words, metaphonological awareness refers to a more explicit ability to manipulate and identify the constituent linguistic units in words, a consequence of exposure to reading and spelling. Typical tasks to measure epiphonological awareness are the syllable tapping, rhyme judgment and oddity tasks. Metaphonological tasks include phoneme blending, phoneme change or deletion. While both epi- and metaphonological awareness are usually assessed orally with hearing children, tasks specifically designed for deaf children typically measure epiphonological awareness using a picture-based format. Therefore, the reliability of phoneme-level awareness in deaf subjects is questionable or at least problematic when used for comparisons with hearing ones. The epiphonological awareness measures address a very important processing level contributing to spelling. Spelling, contrary to reading, always needs an active access to grapheme sequences easy to acquire or challenged by perceptual inconsistencies or contrasts of ambivalent perception of suboptimal features of spoken utterances such as vowel duration, geminates or liquid assimilations.

There is a broad consensus in the literature that orthographic processing skills represent the "ability to form, store, and access the orthographic representations" of words or meaningful parts of words (Stanovich and West, 1989, p. 404). These skills allow advanced readers to read familiar words by sight and have a fast access to meaning associated with the representation of proper sequences of letters in memory. While most of the models on spelling agree on these skills are presumably acquired through reading experience as children develop extensive letter-to-sound knowledge, the individual differences in orthographic skills are discussed as not completely explained by reading experience. One of the first explanations was that of Frith (1985) who argued that differences in orthographic skills might also result from differences in the degree to which children adopt a reading strategy whereby they analyzed or processed all the letters in words. However, this model may not be valid for several non-English languages. Share (1995, p 151) for example stated, that "phonological recoding, by virtue of its self-teaching function, is regarded as critical to successful reading acquisition". Our study on five European orthographies revealed, that the factor load of the different core components of orthographic development were not the same as in English and showed different developmental trajectories (Ziegler et al, 2010).

Several cross-linguistic comparisons were performed in the last decade to assess whether the models describing the use of phonological and orthographic skills developed for anglophone children apply to other alphabetic scripts. It is well known that alphabetic scripts are not all alike as they differ, among other things, in the consistency how letters are mapped into phonology of the language. Orthographies where graphemes consistently represent the same phonemes and speech sounds are consistently represented by the same letters are labelled as shallow or transparent. In contrast, English is characterized by complex and inconsistent correspondences between phonemes and their graphemic representations producing an orthographic system which is polyphonic and polygraphic. Polyphonic because its orthography includes graphemes that can represent more than one phoneme (e.g., i in mint vs. pint; ea in heal vs. health), and polygraphic because it includes some phonemes that can be represented by different graphemes (e.g., /f/ in fish vs. philosophy; /c/ in cat vs. kit). Orthographies such as English are labelled as deep or opaque. Therefore, the question arises whether complexity variations in the grapheme-to-phoneme mappings influence how phonological and orthographic skills contribute to reading and spelling. As research on cross-linguistic differences is growing the interaction of orthography and phonology gets in the focus considering two factors as important, complexity and consistency.

### *Role of phonology in orthographic development*

The recognition of written words is based on the matching of script to lexical representations, which can be achieved through two mechanisms. On the one hand, the letter strings can be mapped to the lexical-semantic representations through orthographic coding, this is called direct or lexical access. Accordingly, reading models that place emphasis on the orthographic system (Seidenberg, 1985) assume a separate orthographic lexicon exists and consider the semantic system lexically accessible attributing only a post-lexical role to phonology. On the other hand, the correspondence of orthographic and phonological code contributes to the emergence of lexical-semantic representation enabling an indirect or sub-lexical access. Most of the reading models that place emphasis on the phonological system (see Ramus et al, 2003) consider this mechanism exclusive where phonology mediates the access to the semantic system. In addition, there are models (Harm et al, 2004; Perry et al 2010; Plaut et al., 1996) that consider the two matching mechanisms as complementary considering their relative importance or function that may change. Less is known about the role of phonology in deaf children and its contribution to reading.

One of the influential studies on deaf students revealed that the majority reads at grade 4 level or below (Qi and Mitchell, 2012). However, this does not necessarily mean that deafness is an insurmountable obstacle to the acquisition of reading. Approximately 10% of the deaf college students investigated could read at an age-appropriate level (Qi & Mitchell, 2012). Although the most obvious explanation of the reading problems is the difficulty or total lack of phonological access, we have to consider that deafness does not affect the phonological access only as it has a measurable impact on language acquisition, including vocabulary growth and differentiation. A closer analysis of the core components of reading may give a more sophisticated picture on the real nature of reading and reading difficulties in general and especially in deaf children.

Studies focusing on the phonological factors of reading examined phonological spelling, awareness, and transcoding. Moreover, most of the spelling studies focused on spelling errors only and produced contradictory results (Olson and Caramazza, 2004; Harris and Moreno, 2006; Hayes et al 2011; Roy et al, 2015). For example, in the study of Hanson, Shankweiler and Fischer (1983) deaf participants showed an elevated sensitivity to the orthographic rules contradicting to their main result found hearing participants where the errors were phonological in nature. However, as the data of Olson and Caramazza (2004) revealed, while 75% of the spelling errors of hearing participants was phonological in nature, 80% of the errors of deaf participants was not. Phonological transparency had no effect on the performance of deaf participants contrary to a strong effect found in hearing participants.

Several studies have reported that deaf participants underperformed the hearing ones in phonological awareness tests (Koo et al, 2008; Sterne & Goswami, 2000), though better results were found than expected, e.g. scores higher than in random guessing (Kyle and Harris, 2006, 2010; Narr, 2008). The conclusion drawn by all the authors cited was that a certain level of phonological awareness was reached by the deaf. However, whether phonology or a similar processing may play any role in reading development of deaf subjects depends on how we define phonology. According to the traditional view phonology is a systematic organization of sounds in spoken languages. However, the principles of phonological analysis can also be seen as a general analytical tool and be applied for sign languages in spite of the fact that the sub-lexical units are not instantiated as speech sounds. As Brentari, Fenlon and Cormier (2018, p 1) suggest this definition of phonology "helps us see that the term covers all phenomena organized by constituents such as the syllable, the phonological word, and the higher-level prosodic units, as well as the structural primitives such as features, timing units, and autosegmental tiers, and it does not matter if the content is vocal or manual." However, in the phonology of spoken languages there are phonological processes or rules referred to a whole class of phonemes in terms of a property or set of properties that they share. Although sign languages do not provide us with abundant evidence of this sort, the concept of an abstract, modality-independent phonology may influence our approach in investigating how reading develops in deaf subjects (see Brentari, 2019).

A broad consensus exists in the reading literature about the importance of phonological awareness that correlates with reading acquisition in hearing subjects though to a different extent according to orthographic transparency (see Ziegler et al, 2010). On the contrary, results published on the performance of deaf participants are far from consistent. While some studies have found a relationship between phonological awareness and word reading (Domínguez et al, 2014; Dyer et al., 2003; Koo et al., 2008), others have failed to confirm any (Izzo, 2002; Kyle and Harris, 2006, 2010; McQuarrie and Parrila, 2009; Narr, 2008). We may explain these differences by the age of the participants, since the studies that found a relationship included adolescents and young adults, e.g. university students (Domínguez et al., 2014; Dyer et al, 2003; Harris and Beech, 1998; Koo et al., 2008). However, if phonological awareness played an important role in reading acquisition of the deaf children, correlations should have been found between phonological awareness and reading scores. This, however, was not the case in many studies (Izzo, 2002; Kyle and Harris, 2006, 2010; Narr, 2008). Moreover, the results of Kyle and Harris (2010) showed that in deaf children lipreading and vocabulary had a predictive power on literacy development and only an earlier reading ability was related to later phonological awareness skills. The authors followed the development of reading ability in a group of 29 deaf children over a 3-year period (first assessment at the age of 7–8 years) and literacy, cognitive and language tasks were performed at every 12th month. However, the participants were either deaf or hard of hearing, and this might contribute to the variation of the results as children who had the most age-appropriate reading skills tended to have less severe hearing losses, earlier diagnoses and preferred to communicate through speech. Although the authors emphasize the role for speechreading, vocabulary and phonological awareness, no valid conclusions can be drawn on the literacy development of deaf children because of extremely heterogeneity of the participants.

The disparity of skills reported by Kyle and Harris (2006, 2010, 2011) might be labeled as predictors of reading and spelling in deaf children, although those investigated in the cited studies showed a high variation, especially in the one published in 2011. While all children had a severe or profound prelingual sensory-neural hearing loss with a mean of 100 dB (75–120 dB) across four frequencies, they visited different schools including specialist schools for the deaf and hearing-impaired units attached to mainstream schools using very different teaching methods (spoken English only, Cued Speech, English Sign Language). Moreover, on third of the children were fitted with cochlear implants at different age (2.5 to 5 years) and two third wore digital hearing aids. The language and communication background of the children also varied to a large extent and only one third was taught by sign language and 2 of the 24 were bilingual. Therefore, the authors' conclusion "on the relationship between reading and phonological skills in deaf children is mediated by speechreading until the underlying phonological representations are strong enough to support reading" needs a cautious consideration as how phonology should be understood is not defined.

As it was mentioned above the development of spelling relies on epiphonological awareness. Unfortunately, the literature on deaf children's spelling development is even sparser than that for reading. Moreover, most of the studies available in the literature are cross-sectional so that the conclusions to draw are limited because of the high variation in hearing status and use of sign language. However, the main findings have been that deaf children's spelling ability was somewhat less affected by their hearing than their reading ability (Aaron et al, 1998; Burden and Campbell, 1994; Harris and Moreno, 2004). Moores and Sweet (1990) for example reported on a group of deaf adolescents of 16- to 17-years who had a reading comprehension age of 11–12 years and a spelling age of 13–14 years. Other studies have observed higher level spelling performance in deaf children than predicted from their reading ability (Burden and Campbell, 1994; Harris and Moreno, 2004).

## *Interaction of phonology and orthography in spoken language bilinguals*

We may assume that phonology and orthography of the two languages used by bilinguals interact in reading and spelling. Indeed, several studies have shown cross-linguistic orthographic interferences in perception, comprehension and acquisition (Grainger and Dijkstra, 1992; Van Heuven et al, Jared and Kroll, 2001; Sunderman and Kroll) An influential model that supported these findings was the Dijkstra and van Heuven's (2002) Bilingual Interactive Activation Plus (BIA+) model of visual word recognition in bilinguals suggesting that bilingual visual word recognition includes sub-lexical, lexical, and semantic units as well as language nodes representing language membership information. The model predicted that orthographic, phonological and semantic representations were decoded in the initial phase of processing and an integrated outcome called 'task schema' served the final lexical decision. The model assumed that orthographic and phonological information of both languages underwent simultaneous activation before lexical decision and resulted in competition. Studies examining these effects (Jared and Kroll, 2001; Sunderman and Kroll, 2006) claimed that proficiency in each language had a great impact on the result and showed a cross-language influence modulated by increasing proficiency in the second language (L2).

Similar, though slightly different results were published by Kroff, Tamargo and Crussias (2018) who used visual world paradigm and eye tracking to investigate the interference of orthographic and phonological mappings with spoken language comprehension in bilinguals. According to their data second language acquisition might influence the dominant L1 as native speakers of Spanish showed a clear effect of orthographic mappings of their less dominant L2 English, providing new insight into the nature of the interaction between orthography and phonology in bilingual speakers. In bilinguals a cross-linguistic activation of lexical items with similar phonology and orthography resulted in a cross-language competition, and both phonological and orthographic features competed for selection, even if their representations were asymmetrical across languages.

The majority of research on the interaction between phonology and orthography in bilinguals used words only, either in behavioral tasks such as lexical decision and naming, or in experiments using eye-tracking, event-related potentials (ERPs), and various brain imaging techniques. Most of the studies have shown that various factors might influence the extent of cross-linguistic interference, such as similarity of orthographic structure such as the linguistic neighbors, interlingual homographs, homophones, or phonological, orthographic and semantic overlaps (cognates, such as the French-English words *plante* and *plant*). As Schwartz, Kroll, and Diaz (2007) showed varying degrees of the orthographic and phonological similarity resulted in distinct effects of cross-linguistic influence. The authors investigated English–Spanish bilinguals in Spanish-only and English-only word naming tasks. Spanish stimuli were also paired with their English translations and separate measures of orthographic and phonological similarity were performed for each pair. The results showed a significantly slower naming for orthographically more similar and phonologically distinct cognates than for those with higher level phonological similarity. The authors interpreted this result as the consequence of feed-forward activation from orthography to phonology across languages accompanied by a less strong feed-back activation.

The role of competing orthographic information and its mapping relationship to phonology in bilinguals does not belong to the main line of bilingual studies. However, this is especially interesting in light of the second language acquisition (SLA) studies which showed that the assumed interaction of L1 and L2 orthography either facilitated or hindered the lexical acquisition in L2. Moreover, Erdener and Burnham (2005), who investigated the effect of different L1 orthographic systems on L2 speech perception and production with focus on orthographic depth found intriguing differences. Participants included a group of Turkish L1 (transparent orthography) speakers and a group of Australian English L1 (opaque orthography) speakers, tested on the production of nonwords using

Irish (opaque) or Spanish (transparent) orthographic conventions. In each condition, participants were given varying combinations of auditory, visual, and orthographic information. Results showed that in the conditions where orthography was not provided, the Turkish L1 participants consistently outperformed their Australian English L1 counterparts. However, in orthographic conditions, a general pattern emerged. With Spanish stimuli, a facilitation effect was shown by the Turkish L1 speakers, whereas with Irish stimuli, this effect was attenuated. The authors concluded that while the Turkish L1 speakers relied more on orthography, the Australian English L1 speakers used alternative visual cues, seen as a consequence of experience with grapheme–phoneme correspondence inconsistency in their L1 system. The authors suggested that the orthographic system of L1 might modulate the L2 orthography-based speech perception and production. The success of this integration was suggested to depend on the corresponding nature of the L2.

Escudero, Simon and Mulak (2014) investigated how incongruency between orthographic mappings influenced acquisition in Spanish L1 speakers with prior experience with L2 Dutch. They used minimal pairs of Dutch pseudowords different in vowel only. (e.g., 'pag'– 'puug'): The stimuli were presented with line drawings of non-objects representing each pseudoword. AS there is a clear difference in the orthographic representation of vowels in Spanish and Dutch, minimal pairs of perceptually easy or perceptually difficult for Spanish learners could be produced. The different groups receive auditory stimuli only or auditory plus orthographic stimuli. The results revealed that the extra orthographic information had a negative effect on the participants performance when the grapheme–phoneme correspondence was incongruent across languages and a positive effect when it was congruent. These results are in line with the previous studies showing that perception (Escudero and Wanrooij, 2010) and word learning (Hayes-Harb et al, 2010; Escudero et al, 2014) are under the influence of orthographic mapping that contributes to lexical competition in bilinguals.

### *Orthography and phonology in spoken-sign language bilinguals*

Research on spoken language sign language bilingualism addresses the same linguistic, psychological and educational issues as the broader field of bilingualism does. However, a solid understanding of this special bilingualism requires familiarity with the relevant issues in each of these domains of bilingualism in general. However, it is of prime importance to understand the variables that distinguish sign language-spoken language bilingualism from spoken one. Whereas spoken languages are communicated through the auditory-vocal modality, sign languages are communicated through the visual-spatial modality. When both sign language and spoken language are acquired, the two distinct modalities allow extraordinary options for language mixing. The use of spoken and sign language allows the combination of two languages not only sequentially, as in spoken language mixing, but both sequentially and simultaneously.

Studies on spoken language bilingualism aim at explaining the language mixing phenomena by identifying universal linguistic principles that constrain this language mixing (see Bhatia & Ritchie, 1996). However, this type of studies on spoken language (SPL)- sign language (SL) bilingualism are practically non-existent. This has many reasons. First, there are very few SPL-SL bilinguals within the deaf community. These persons have generally had severely restricted access to spoken language input in the auditory-visual modality substituted. Thus, unlike hearing bilinguals, deaf and hard of hearing bilinguals are challenged in their attainment of sign language as well as that of spoken language for which they should have been exposed according to their hearing status. However, the educational practice in Hungary avoided sign language teaching and forced oral education in deaf children. With this practice Hungary as many other countries in Europe and the USA followed the resolutions of the Second International Conference of Deaf Educators (in practice the first one) held in Milan in 1880, commonly known as "the Milan Convention" (see Gallaudet, 1881). It was declared that oral education (oralism) was superior to manual education and passed a resolution banning the use of sign language in schools. As a consequence, schools switched to using speech therapy without sign language as a method of education for the deaf. A formal apology was made by the board at the 21st International Congress on Education of the Deaf in 2010 referring to this practice as discrimination and violation of human and constitutional rights. As a result of limited sign language teaching at schools for decades, spoken language – sign language bilingualism is rare.

Hearing persons have access to both modalities and are not disadvantaged on the basis of their hearing status. However, as with spoken language bilinguals, the bilingual competencies of both deaf and hearing SL-SPL bilinguals are influenced by sensitive period effects. With respect to the acquisition of ASL as an L1, Lillo-Martin (1999) summarized the existing body of research on the acquisition of ASL by deaf children of deaf parents who used ASL (only 5–10% of deaf children). From this body of research, Lillo-Martin concluded that deaf children acquired ASL in much the same way as hearing children acquired spoken languages. Deaf children followed the same acquisitional sequences at roughly the same ages as hearing children. However, the vast majority of deaf children could not acquire sign language for decades. and this was valid for many countries. The American Sign Language (ASL) knowledge as L1 versus L2 ASL yielded several differences (see Fischer, 1998). L2 ASL is often difficult to define because non-native but early learners (ages 5–10) of ASL often attain native-like knowledge of ASL, as compared to late learners e.g. those acquiring ASL after puberty. Despite these differences, the accessibility of the visual-spatial modality establishes ASL as the primary language of many deaf persons.

Already the early studies on deaf children's acquisition of English have shown that restricted access to the audio-visual modality had consequences for the attainment of English knowledge (Quigley and King, 1980). They reported that, on average, the English knowledge of 18-year-old deaf students was less developed than that of 8-year-old hearing students. The possible reason of this lower level performance was that English as the first or only language deaf children was exposed providing a restricted access to the audio-visual modality resulted in English knowledge that simulated L2 knowledge named by Berent (1988, 1996) as "L1.5 acquisition". Therefore, the L1 and L2 labels used in the bilingualism literature is often difficult to apply. On modality grounds alone, ASL is sometimes regarded by members of the deaf community and proponents of bilingual models of deaf education as the L1 and the spoken language as the L2 of deaf persons, despite the age of exposure or levels of competency in the two languages.

### *Role of modality in bimodal bilingualism*

Sign language-spoken language bilingualism is by definition bimodal bilingualism. The term bimodal is used as the communication is spoken languages use the auditory-oral and in sign language the visual-gestural modality. Although both modalities are anatomically pre-wired to enable the access to brain networks in service of the language faculty, the modality-specific properties contribute to different constrains in the otherwise similar language systems. However, the linguistic approach is that in spite of the fact that the two languages, e.g. spoken and sign rely on specific mechanisms available within their respective modalities, they are fundamentally similar. Therefore, the linguistic, psychological and neuroscientific investigation of language development bimodal bilingualism would be of high importance. However, studies on bimodal bilingualism are rare and one of the reasons is that the number of sign languages are rather limited as compared to that of spoken languages (Padden, 2011).

There are several different aspects of bimodal bilingualism that should be considered when compared with those of unimodal bilingualism. The bimodality of sign-spoken language bilingualism includes both deaf and hearing individuals, and it is obvious to assume that their hearing status and associated factors play an important role on the basis of relative access to representation in the different modalities (see Ann, 2001; Berent, 2006). Whereas a hearing person has access to linguistic communication within both modalities, deaf person may rely only on the visual-gestural modality. Depending on the extent of hearing loss (Stach, 2008), a bimodal bilingual may have little or no natural access to the auditory component of spoken language communication. As a consequence, bimodal bilingualism research has to pay attention to these differences. For deaf bimodal bilinguals for example, many variables influence the acquisition, such as the onset of deafness, degree of hearing loss, age of acquisition of spoken and sign language, access to spoken only or compensatory visual input, type and quality of early education, trajectory of literacy development and reading level (Berent, 1996, 2009; Emmorey et al, 1995). Consequently, all of these factors have an impact on the development of spoken language and sign language phonology representing one with routes in speech and another one more abstract in nature (see above) respectively. However, how phonology assumed as similar on the abstract level for spoken and sign language and different in realization contributes to reading development, is not clear yet. While we may assume, that spoken and sign language phonologies are fundamentally the same, the orthographic development is different in spite of the fact that bimodal bilinguals have to acquire one reading system only and not two as unimodal bilinguals. Therefore, it is of high importance to learn more about the orthographic development of those children who represent a 5–10 % of children with balanced bimodal bilingualism.

## *Neural consequences of bimodal bilingualism*

The language-learning aptitude defined as innate and fixed talent for learning languages (Neufeld, 1979) became an outdated concept due to epigenetic and neuroscientific data collected in the last twenty years. It is broadly accepted by the bilingualism research community that several biological factors, and not only aptitude, as well as many other aspects of L2 acquisition contribute to the bilingual development such as age of acquisition, time spent using the L2, quality of input in the L2, as well as the impact of socioeconomic status. All these constructs, among others, contribute to the ultimate attainment of L2 proficiency (Dörnyei and Skehan, 2003; Ross et al, 2002). Moreover, it is worth to make clear about that aptitude and proficiency are two distinct constrains as aptitude refers to the ability to develop a skill and proficiency to the degree of competence acquired. However, the concepts are related as individuals with high levels L2 proficiency show high scores in the language aptitude tests. Although proficiency and aptitude measures target similar though only overlapping and fully identical processes, the recent approach used in several bilingualism studies is to assess the L1-L2 proficiency difference and classify the bilingual participants as balanced or unbalance according to the discrepancy found.

The early neuroscientific studies provided more similar data on the bilingual brain than the recent ones (for review see Csépe, 2017). The contradiction available between the recent findings is related to the complexity of the bilingual language use as well as on the variety and reliability of behavioral measures used for selecting bilinguals. There are several problematic factors including aptitude, proficiency, age of acquisition. All neuroscientific measures, structural or functional, provide data influenced by biological factors such as maturation, anatomical constrains, individual experience, education. Archila-Suerte and his coworkers (2018) investigated bilingual children classified as balanced or unbalanced with magnetic resonance imaging (MRI). The behavioral measures used for classification were standardized language assessments tests receptive and expressive knowledge of the L1 and L2 and not the broadly applied aptitude tests using traditional metacognitive tasks such as phonological working memory or analytical reasoning (Kiss and Nikolov, 2005; Paradis, 2011). They also used a measure of L2 accent in order to validate the balanced vs. unbalanced classification. Although the Spanish-English bilingual children (6–13 years old) investigated were comparable for age, age of acquisition, years of education, parental education, L1 and L2 use, and L1 proficiency, they were significantly different in L2 proficiency. That is, while balanced bilinguals were highly proficient in both languages, unbalanced bilinguals were only proficient in the L1but significantly less proficient in the L2. Generally, children in the balanced group were considered to be more bilingual than children in the unbalanced group. Balanced bilingual did not necessarily high proficiency in both languages.

Archila-Suerte and his coworkers (2018) identified intriguing neuroanatomical differences between children with balanced vs. unbalanced bilingualism. Balanced bilinguals had thinner cortices of the left transverse superior temporal gyrus, the inferior and middle frontal gyri as compared to unbalanced bilinguals. Moreover, for children with unbalanced bilingualism, a more expressed foreign accent in the L2 negatively correlated with cortical surface area of the middle frontal gyrus and the superior central sulcus. The *cortical thickness, changing with age,* was significantly different between the groups after controlling for age so that cortical thinning can be attributed to increased proficiency in both languages. This could suggest that bilingualism is influencing brain development. This, however, contradicts to a previous study showing significant thickening with higher L2 proficiency (Mårtensson et al., 2012). One of the main differences is that Mårtensson and his coworkers (2012) investigated adult bilinguals highly trained as interpreters and examined L2 proficiency only, whereas Archila-Suerte et al (2018) investigated young children with less developed language skills and examined overall proficiency within each language. Their results also showed that only one aspect of proficiency e.g. the degree of accent is associated with cortical surface area. However, as previous studies revealed cortical thickness of the superior temporal gyrus is linked to sound perception in both speech (Wong et al, 2008) and music (Wengenroth et al, 2014). Moreover, the morphological variability of this cortical region is heritable (Cai et al., 2014; Thompson et al., 2001), suggesting the biological predisposition for the degree of how successfully children may acquire phonology of the L2.

One of the evergreen questions of the brain studies on bilingualism is whether the neural systems that support language processing in each language are separate or overlapping. There is a general consensus that the two languages spoken by bilinguals share the same brain regions, so that a high degree of neural convergence can be found, particularly for proficient and early bilinguals (for review see Buchweitz and Prat, 2013). Moreover, lesion studies and neuroimaging measures support the view that the neural network of signed and spoken language processing is the same to a large extent (for review see MacSweeney et al, 2008; Emmorey, 2002). In both spoken and signed language comprehension is associated with activation of the superior temporal cortices, including regions responsible for auditory processing and production with that of the left-lateralized fronto-temporal network. Although most of the studies compared deaf native signers and hearing monolingual speakers, similarities between them and hearing bimodal bilinguals could also be shown (MacSweeney et al, 2002). However, there are serious concerns about the reliability of these results because bimodal bilingualism is qualitatively different from deaf signing. Moreover, conclusions of the linguistic studies on a general, modality-independent representation are not fully supported by the recent neuroscientific investigations. There are new data showing that the neural representation of spoken and sign languages differ (Corina et al, 2013). Moreover, studies on direct contrasts between speech and sign in bimodal bilinguals reveal striking differences between the sensory-motor neural resources required to produce and comprehend languages in different modalities (Emmorey et al, 2014). It seems that the bimodal bilingual brain differs from the unimodal bilingual brain in the extent of neural overlap of the two languages, e.g. less extended for bimodal bilinguals than for unimodal ones. It makes sense as language comprehension of sign language relies on visual-spatial coding and for that the parieto-occipital cortices are engaged to a greater extent as compared to speech comprehension (Emmorey et al, 2014).

Zou et al (2012) suggested that bimodal bilinguals may develop and control more complex neural networks than unimodal bilinguals. However, to our best knowledge no neuroscientific study has been performed to compare language switching of bimodal and unimodal bilinguals. unimodal bilinguals exhibit increased grey matter density in the left inferior parietal lobe (Mechelli et al, 2004), two further studies comparing hearing bimodal bilinguals with monolingual speakers failed to detect differences in grey matter volume of the same brain region (Olulade et al, 2014; Zou et al, 2012). A possible explanation for the differences found that unimodal bilinguals acquire two phonological systems within the same modality, so that the left inferior parietal lobe supporting phonological working memory is much more engaged in unimodal than in hearing bimodal bilinguals. Because phonology plays an important role in reading acquisition it is of high importance to investigate the similarities differences of the two phonological systems e.g. that of the signed and spoken languages. As it is clear from the literature on bimodal bilingualism the spoken and sign language phonology show non-overlapping features and it is not clear either how mouthing e.g. words often produced with signs (e.g., Boyes Braem and Sutton-Spence, 2001) contributes to sign language phonology.

Finally, we have to note there are even more open questions about the neural systems that underlie bimodal bilingual language processing than in the linguistic or psycholinguistic approach on bimodal bilingual language acquisition in both deaf and hearing children or L2 acquisition. The neuroscientific studies on bimodal bilinguals illustrate how dynamic neural changes support the emerging links between spoken and sign languages at different processing levels, and the correspondence of spoken and sign phonology, mental lexicon and semantics should be revisited. However, one conclusion is clear, the resolutions of the Milan Convention should be forgotten and bilingual education of the deaf and hard of hearing children is the only right solution. At the same time, further studies are needed to shed light on the nature of difficulties deaf children face in reading acquisition.

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