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REVIEW AND SYNTHESIS

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Sign language in d/deaf students' spoken/written language development: A research synthesis and meta-analysis of cross-linguistic correlation coefficients

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Abstract

This paper presents the first systematic review and meta-analysis on cross-linguistic correlations between sign language and spoken/written language competences in bilingual d/Deaf learners. A total of 202 effect sizes were identified based on 70 independent samples that appeared in 52 studies from 1981 to 2023 ($N=3570$). The effect sizes involved seven sign language correlates (e.g., fingerspelling, phonological awareness [PA], lexico-semantic knowledge) and eight spoken/written language correlates (e.g., PA, lexico-semantic knowledge, word reading, reading comprehension). Estimated mean correlations of 26 cross-linguistic relationships ranged from $r=0.322$ ($p<0.001$) for sign language PA and reading comprehension to $r=0.645$ ($p<0.001$) for fingerspelling and word reading. Among other moderators, age/grade (elementary, secondary, vs. university/adult), signer status (native vs. non-native), program type (bilingual vs. Total Communication/SimCom), and task type (passage vs. sentence comprehension) either showed significant moderation effects or resulted in differing size (small, medium vs. large) in the correlation coefficients among subgroups of primary studies. The meta-analytic findings lend support to the legitimate application of linguistic interdependence, common underlying proficiency, cross-linguistic transfer facilitation, and their associated constructs to the educational development of signing/bimodal bilingual learners. The moderator analysis results, in particular, have shed light on the conditioning of linguistic interdependence and transfer and expanded current understandings about the complexity of the issue and its practical implications in bilingual deaf education.

KEYWORDS

bilingual deaf education, bimodal bilingual, cross-linguistic transfer facilitation, linguistic interdependence, meta-analysis

Context and implications

Rationale for this study

There are debates on roles of sign language in d/Deaf children's spoken language and literacy development. Correlations between sign language and spoken/written language competences should be meta-analysed.

Why the new findings matter?

Meta-analytic findings contribute to the debates and understandings about the complexity and conditioning of linguistic independence between sign language and spoken/written language competences.

Implications for practitioners and policy makers

Sign language plays important roles in the education of d/Deaf children. It is important that educational policy and planning for d/Deaf children have sign bilingualism as a goal. Curriculum and instruction in deaf education should entail opportunities for children to actively use sign language. More importantly, sign language competences could and should be instructional goals to promote cross-linguistic transfer facilitation in d/Deaf children's reading development. Instructional goals on sign language need to be nuanced and differentiated, considering skill types, children's developmental stage, sign language proficiency, and so forth.

One of the biggest debates in the education of d/Deaf children centres on how sign language may, or may not, benefit the development of spoken language and literacy (e.g., vocabulary, word reading, and reading comprehension). Cummins' Linguistic Interdependence Hypothesis (LIH), which underscores cross-linguistic transfer of literacy-related competences in (hearing) bilingual or minoritised children, has often been the vehicle of the debate. While many, including Cummins himself, have contended on a legitimate application of the tenets of the LIH to signing d/Deaf children (e.g., Cummins, 2007, 2021), and the LIH is often cited as an important underpinning of sign bilingual education (Chamberlain & Mayberry, 2000;

Swanwick, 2016), others have disagreed, on the ground that sign language is visual–spatial and does not have a widely accepted written form (which shows a stark contrast to literacy acquisition in hearing bilinguals) (Mayer & Akamatsu, 1999; Mayer & Wells, 1996).

The debate has continued despite accumulated evidence for positive correlations between sign language and spoken/written language competences for d/Deaf bilinguals over the past few decades. There are still many issues that remain to be understood about 'interdependence' and its associated constructs such as common underlying proficiency (CUP) in the education of signing d/Deaf children. It is now well understood, at least based on existing theorisations and findings on hearing bilinguals, that linguistic interdependence or cross-linguistic transfer occurs under certain conditions and could be subject to potential modulation of various factors related to the languages in question, bilingual readers themselves, the skills in question, the educational context, among many others (Chung et al., 2019; Cummins, 2021; Hipfner-Boucher & Chen, 2016; Ke et al., 2023; Koda, 2005, 2008). It is thus essential that learner-internal and external heterogeneities be considered when studying sign language and spoken/written language interdependence and making sense of their associations in d/Deaf bilinguals; yet these issues have often received limited attention in individual primary studies.

To address this gap and expand current understandings (and perhaps debates as well) about sign language in d/Deaf bilinguals' spoken/written language development, we conducted a systematic review and meta-analysis on studies that reported correlational associations between measured competences in sign language as well as spoken/written language. This review and meta-analysis directly addresses the fundamental questions that Padden (2008) raised about sign language in the education of d/Deaf children but have not yet been adequately understood: 'Can sign language instead play a role in reading development? If so, how is this achieved in young deaf children? Which elements of sign language link to comparable elements in spoken language that we already know contribute to reading development?' (p. xiii). The findings will contribute toward answering these questions and enrich current understandings about the LIH, CUP and cross-linguistic transfer from the lens of bimodal bilingualism. They will also shed light on bilingual approaches to educating d/Deaf children in regard to what sign language competences could and should perhaps be capitalised on to promote d/Deaf children's literacy development through 'teaching for transfer' (Ballinger et al., 2020; Cummins, 2021).

LINGUISTIC INTERDEPENDENCE, TRANSFER FACILITATION, AND EDUCATION OF BILINGUAL CHILDREN

Cummins' Linguistic Interdependence Hypothesis

The most influential theorisation of cross-linguistic issues in the education of bilingual children is perhaps the LIH proposed by Cummins (e.g., Cummins, 1979, 1991, 2000, 2021). In his earliest articulation on the LIH, Cummins (1979) argued that 'the level of L2 competences which a bilingual child attains is partially a function of the type of competence that child has developed in L1 at the time when intensive exposure to L2 begins' (p. 233). To explain the challenges bilingual minoritised students faced in schools (largely in the North American context then), Cummins distinguished between Basic Interpersonal Communicative Skills (BICS) and Cognitive/Academic Language Proficiency (CALP). While BICS is characterised by context-embedded communication that may not pose a challenge for bilingual children in a language-majority environment, CALP involves context-reduced, cognitively demanding language. CALP, compared to BICS, can be particularly challenging and takes a longer time to develop in a target language. Nonetheless, CALP may stand for CUP that can transfer across languages, such as from children's home language to their development of English literacy in North America.

Among the early critiques on the LIH and its associated constructs, which Cummins later discussed and contested (e.g., Cummins, 2000, 2021), was a concern about the lack of specificity on the CUP (Chung et al., 2019; Hipfner-Boucher & Chen, 2016). In other words, what are the specific competences that constitute the CUP or the 'common core' of bilingual proficiency that are not distinctive surface L1 and L2 features? According to Cummins (2021), CALP represents 'a *fusion* of conceptual, linguistic, and academic knowledge' (p. 8; italicised emphasis original); and 'the common underlying proficiency makes possible transfer of concepts, skills, and learning strategies across languages' (p. 9). Cummins (2021) further contends that there are six major types of cross-linguistic transfer, including conceptual elements, specific linguistic elements, more general morphological awareness (MA), phonological awareness (PA), metacognitive and metalinguistic learning strategies, and pragmatic aspects of language use (p. 32). Cummins has also maintained that transfer of competences constituting the CUP can be bidirectional between languages. How transfer happens can depend on many factors including a 'threshold' of proficiency in the L1/L2 as well as the broad sociolinguistic and educational contexts (e.g., instructional programme).

Cross-linguistic transfer facilitation in bilingual reading

The LIH and its associated constructs have subsequently guided many discussions and debates on policy and practice related to bilingual children and their educational development (e.g., August & Shanahan, 2006; Cummins, 2000, 2021). They have also motivated further theoretical effort on understanding cross-linguistic transfer in the context of L2 reading and bilingual education (Chung et al., 2019; Geva & Ryan, 1993; Koda, 2005, 2008). The Transfer Facilitation Model (TFM; Koda, 2005, 2008; see also Koda et al., 2014), as a notable example of further theoretical development, aims to explicate the complexity, specificity and conditions of cross-linguistic transfer with a fine-grained focus on metalinguistic awareness in L2/bilingual reading development. Adopting the connectionist perspective of skill development, the TFM argues that the development of L2 reading, which is 'a complex, multidimensional pursuit, entailing a large number of sub-component processes' (Koda, 2005, p. 312), can be regarded as a procedural amalgamation that evolves from cross-linguistic interactions between transferred L1 competences and L2 input. Learners' L2 (sub-)lexical processing experience and their L1 skills are thus both critically important for the development of L2 reading and its related abilities.

Over the past decades, extant empirical work has also been conducted that aimed to explore linguistic interdependence, CUP, and the mechanisms and conditions of cross-linguistic transfer among (hearing) bilingual/L2 learners. Based on different 'perspectives' (Hipfner-Boucher & Chen, 2016), including cross-linguistic correlations measured of competences in two languages, those studies overall support the tenets of the LIH and the TFM (for narrative reviews, see Chung et al., 2019; Cummins, 2021; Hipfner-Boucher & Chen, 2016). For example, not only were cross-linguistic correlations found between corresponding sub-skills such as PA and MA in L1 and L2 (that is, construct-level transfer), but some direct association of L1 subskills with reading abilities in L2 (e.g., word reading and reading comprehension) (that is, crossover effects) (see Hipfner-Boucher & Chen, 2016). This body of the literature, nevertheless, also revealed the complexity of linguistic interdependence and transfer concerning the strength, mechanisms and directionality of cross-linguistic associations. It also demonstrated that transfer is conditioned on various factors such as L1-L2 distance, L1/L2 proficiency, language complexity, education settings and research methodology (Chung et al., 2019; Hipfner-Boucher &

Chen, 2016). The LIH and transfer facilitation, and their conditioning and complexity, have also motivated efforts to synthesise the findings in a few meta-analyses of cross-linguistic correlation coefficients (e.g., Branum-Martin et al., 2012; Ke et al., 2021; Melby-Lervåg & Lervåg, 2011; Prevoo et al., 2016). These meta-analyses, however, exclusively focused on hearing bilingual children or L2 learners.

SIGN BILINGUAL EDUCATION AND DEAF CHILDREN'S SPOKEN/WRITTEN LANGUAGE DEVELOPMENT

For decades, interests in and debates on sign language in the education of d/Deaf children have never been abated. In her systematic review on bimodal bilingualism, Swanwick (2016) identified four major themes of research, namely, linguistic aspects of bimodal bilingualism; bimodal bilingual language use; bimodal bilingual literacy development; and bimodal bilingual pedagogies. Of particular relevance to the present review and meta-analysis is the third theme, which is 'a high priority in terms of research and practice development in sign bilingual education' and where debates often exist (Swanwick, 2010, p. 156). Interests and debates have centred on whether developmentally sign language may play a facilitative role in d/Deaf children's literacy development; and if so, how sign language and spoken language may be combined to provide d/Deaf children with the bimodal bilingual experience and promote their educational outcomes (e.g., Cummins, 2007; Knoors & Marschark, 2012; Mayer & Leigh, 2010; Mayer & Wells, 1996; Prinz & Strong, 1998; Scott, 2021; Swanwick, 2016). Perhaps without any surprise, Cummins' LIH and its associated constructs, such as BICS, CALP, CUP and transfer, have often been a vehicle of the discussions and debates, with differing positions on the applicability of these theoretical tenets in the education of d/Deaf children (Chamberlain & Mayberry, 2000; Cummins, 2007, 2021; Mayer & Akamatsu, 1999; Mayer & Wells, 1996).

Critiques on linguistic interdependence and transfer in deaf education

In a hallmark article that was later much critiqued, Mayer and Wells (1996) maintained that the LIH and transfer-induced benefits would not hold true for sign language and literacy development in d/Deaf children. In their earliest discussions, Mayer and colleagues (e.g., Mayer & Akamatsu, 1999; Mayer & Wells, 1996) raised a few major concerns. First, sign language, given its visual and spatial modality, is fundamentally different from spoken language. Second, because sign language does not have a widely accepted written form, there are no reading/writing skills in sign language to have a potential positive impact on the acquisition of those skills in a spoken language. This is incommensurate with the situation in hearing bilinguals who could have prior literacy experience. As Mayer and Akamatsu (1999) argued, 'it [sign language] is not a language that directly mediates the development of text-based literacy in the majority spoken language' (p. 2). Third, most d/Deaf children, considering the fact that about 95% of them are born to hearing parents, may not have the opportunity to develop fluent sign language skills for transfer to happen. Accordingly, 'mastery of skills in the "written mode"' in sign language is barely relevant for d/Deaf children. Mayer and Wells (1996) referred to the last two points as a 'double discontinuity'. Note, however, that Mayer and Wells did not deny that 'ASL [American Sign Language] can develop the cognitive power that would support broad *cognitive* and *conceptual* transfers between ASL and English', but for the reasons being summarised here, 'the possibility of *linguistic* transfer or interdependence is unlikely' (p. 105) (emphasis is ours).

Because of the aforementioned concerns, Mayer and colleagues doubted how sign language may play any positive role or show benefits out of transfer in d/Deaf children's literacy development; and how sign bilingual education programmes, if solely based on transfer-centred claims as maintained by some, may bring about the intended school outcomes for d/Deaf children (Mayer, 2009; Mayer & Leigh, 2010; Mayer & Trezek, 2020). Perhaps in line with their emphasis on instructional goals for spoken language development, Mayer and Akamatsu (1999) further proposed that invented signing systems, 'because of their linear mapping with spoken language, as well as their spatial mapping with signed language', 'may provide a bridge between a native sign language and an English-based natural sign system to build the underpinnings in English (L2) that are necessary for literacy' (p. 3) (see also Paul & Yan, 2023). Knoors and Marschark (2012), likewise, called for a re-examination of bilingual language policy with more consideration of the role of sign-supported speech or simultaneous communication in the twenty-first century (see Scott & Henner, 2021, however, for an example of strong objections to the use of any signing systems as opposed to a natural language such as ASL).

Revisiting the legitimacy of linguistic interdependence and transfer

Mayer and colleagues' discussions later attracted wide attention including much criticism over the past two decades. Many scholars including Cummins himself (e.g., Cummins, 2007, 2021) cited much empirical evidence, including positive cross-linguistic correlations (the focus of the present review and meta-analysis), to demonstrate the relevance of the LIH and its associated constructs and predictions. Findings from psycholinguistic experiments, based on developing as well as skilled readers, also provided converging evidence for sign language activation in written word recognition or during written sentence processing in signing or bimodal bilinguals (Morford et al., 2011; Petitto et al., 2016; Saunders et al., 2024; Villwock et al., 2021). In what follows, we discuss three aspects that are closely related to the LIH, CUP, cross-linguistic transfer and literacy.

First, the interpretation of the LIH, as initially made by Mayer and Wells (1996), seemed too narrow. Cummins (e.g., Cummins, 2007, 2021), for example, discussed how CUP entails a range of transferable resources at the conceptual, metalinguistic, pragmatic and metacognitive levels. Many competences are modality-neutral such as semantic knowledge and pragmatic skills. Morford and colleagues' studies (e.g., Morford et al., 2011; Villwock et al., 2021), for example, showed activation of sign language translations in the processing of spoken/written language words in ASL-English bilingual children as well as adult readers. Inference-making, as another example, is a higher-order skill with critical importance for text reading and comprehension (O'Brien et al., 2015). Yet, by its very nature, inferencing is not a reading or written language skill but a pragmatic skill that is inherent in (modality-neutral) language use and could be transferable across modalities and languages. While phonology is often considered as a modality-specific linguistic aspect, much evidence has been produced supporting activation of sign language phonology in written word processing (see Petitto et al., 2016 for a review).

Second, the mechanisms of linguistic interdependence and cross-linguistic transfer, since the late 1990s (when Mayer and colleagues initially raised their concerns; Mayer & Wells, 1996), have now been much better understood, even though the knowledge advancement seemed to have largely occurred in the literature on hearing/unimodal bilinguals. Mayer and Wells (1996) seemed to presume that L1 transfer facilitation for L2 literacy would have to be directly from corresponding written language skills in L1. In other words, without 'sign language literacy', L1 transfer would barely be of any relevance to literacy acquisition in signing d/Deaf children. This view of Mayer and Wells also appeared to be reflective of the early literature on cross-linguistic approaches to L2 reading where the focus on L1 transfer was largely explored through correlations of *global* constructs such as general proficiency (e.g., Lee & Schallert, 1997). That body of early literature on transfer and L2 reading has later been much critiqued. One major concern was that the design failed to touch on the various underlying processes of becoming literate in L2 and, consequently, what was specifically transferred had remained unknown. In other words, over and beyond an overall conclusion that readers more proficient in their L1 tend to be more so in L2, the contribution was limited toward understanding the nuance, specificity and complexity of linguistic interdependence and transfer facilitation. Likewise, it was difficult, as a result, to generate any nuanced instructional implications over and beyond arguing that bilingual children's literacy in their L1 or home language needs to be promoted.

It is clearly understood now that (L2) reading comprehension is an active meaning construction process that involves the orchestration of a constellation of component processes; and a component approach has now been widely adopted to unravel how various knowledge, skills and strategies underpin reading and comprehension within and across languages (Grabe & Yamashita, 2022). It has been well recognised, as reviewed previously, that L1 subskills—rather than global (reading) proficiency per se—transfer to facilitate corresponding L2 subskills (Hipfner-Boucher & Chen, 2016; Koda, 2008). The latter serves as the intra-lingual basis for L2 literacy development. In other words, there could be an indirect or mediated facilitative effect of some L1 subskills (e.g., PA and MA) on L2 literacy. Some L1 subskills could also demonstrate a direct or crossover effect (Hipfner-Boucher & Chen, 2016), predicting L2 literacy over and above the effects of intra-lingual/L2 subskills. This provides further, if not stronger, evidence on benefits of transfer facilitation in literacy development. It is important to note that transferable subskills do not have to be developed from any prior *literacy* experiences. Some subskills such as MA (e.g., compound structure awareness) and inference-making are by their very nature not written. These are *language* skills emerging from children's early *language* (not just *speech*) use experiences (Hall et al., 2019), even though later literacy experiences would contribute to the refinement of these skills. Accordingly, for signing d/Deaf children, metalinguistic awareness and comprehension skills could be developed from their sign language use experiences and have a positive impact on literacy learning and development. We also point out, however, that not all skills, and not all aspects of any particular skill, are readily transferable. As discussed earlier, the strength of cross-linguistic correlations can vary as a function of a wide range of factors. In other words, the 'linguistic interdependence' between sign language and spoken/written language likely exists under conditions, as in the case of that between two spoken languages in hearing bilinguals. Exploring the conditions is an important goal of the present review and meta-analysis to advance debates on sign bilingual education policy and practice.

Finally, Mayer and Wells (1996) argued that 'for facilitation in L2 literacy learning to occur, the learner must have *mastered* the compatible literacy skills in his or her first languages' (p. 94; emphasis is ours). The LIH, the TFM and other theoretical accounts alike, all underscore that the learner needs to have a 'good' L1 foundation or a 'threshold' of L1 proficiency for transfer to happen. It is still unclear, however, how 'good' the foundation would need to be and what the 'threshold', if any, would be like. Nevertheless, skill mastery or automaticity in L1 skills does not seem to be a necessary condition (Chung et al., 2019). In fact, there is much evidence now, albeit largely based on hearing bilingual readers, that transfer can happen in children with varied levels of L1 proficiency. For example, L1 PA can transfer to facilitate early English reading acquisition among young, Spanish-speaking children, including those who may not have received any formal Spanish literacy experience (Dickinson et al., 2004; Míguez-Álvarez et al., 2021). In relation to Mayer and Wells' (1996) concern about the quantity and quality of sign language exposure, an important empirical question, however, does seem to exist on how d/Deaf children's sign language proficiency or level of sign language experience may impact the strength of any cross-linguistic association between sign language spoken/written language competences. This issue did not seem to have been directly tested in primary studies but is an important goal of the present meta-analysis.

Active debates on the issues that have been discussed so far have continued in the field of sign bilingualism and deaf education (Mayer & Trezek, 2023). In fact, such has been the case despite much empirical evidence accumulated over the past decades on positive cross-linguistic correlations of sign language with spoken language and literacy competences. It is thus urgent that systematic reviews of this body of empirical work be conducted to shed light on cross-modal, cross-linguistic relationships and unravel how various factors may have an impact on the associations. Despite a number of narrative reviews and discussions on bilingual education for d/Deaf children where roles of sign language are underscored (e.g., Chamberlain & Mayberry, 2000; Cummins, 2007; Grosjean, 2010; Sanzo, 2022; Scott, 2021; Swanwick, 2016; Wilbur, 2000), systematic reviews focused on cross-linguistic associations between sign language and spoken/written language competence are rare, not to mention meta-analysis of correlation coefficients. Paul and Yan (2023) intended to systematically review empirical studies concerning the effects of ASL on English reading proficiency and eventually selected some articles for their 'professional review'. The review importantly covered some studies on cross-linguistic correlations between ASL and English reading but did not seem to have included all possible studies of this type. Likewise, the review focused on ASL and English only and did not meta-analyse any findings. The authors noted that some learner-intrinsic (e.g., socio-demographic background) and extrinsic (e.g., programme characteristics) factors may moderate study findings, and called for future research attention to those factors. No moderation effects, however, were tested to reveal how, if at all, different factors may explain heterogeneities in study findings.

PRESENT REVIEW AND META-ANALYSIS

This review and meta-analysis was guided by a broad, resource-sharing perspective that any competences in sign language may potentially serve as a resource for the development of spoken/written language. This approach aligns with the theoretical tenets reviewed earlier on sign bilingualism and the education of d/Deaf children. It was adopted also based on a pragmatic consideration that the general landscape of cross-linguistic correlation-based studies on signing d/Deaf learners was unknown; it is urgent to show the landscape through the review rather than to just focus narrowly on any specific set of skills as existing meta-analyses on hearing bilingual readers did (e.g., Branum-Martin et al., 2012; Ke et al., 2023). Specifically, this review and meta-analysis aims to answer the following questions:

1. What competences have been found to correlate between sign language and spoken/written language in the literature?
2. To what extent do different sign language competences correlate with those of spoken/written language?
3. How might the cross-linguistic correlations between sign language and spoken/written language competences differ across primary studies depending on various factors?

METHODS

Literature search, screening and inclusion/exclusion criteria

Both database and supplemental searches were conducted to identify primary studies for this review and meta-analysis. For database searches, we referred to ERIC, Web of Science, APA PsycInfo, ProQuest Central (linguistics database only), and ProQuest Dissertations & Theses Global. The last database was purposefully included to cover unpublished doctoral dissertations, which were argued to be an important source of information on deaf education (Andrews et al., 2015). These database searches were not restricted to journal articles, because some important studies were known to be published in well-known edited volumes (e.g., Chamberlain et al., 2000; Plaza-Pust & Morales-López, 2008). For all database searches, the same combination of key terms was applied—that is: "deaf" or "hard of hearing" AND "sign language" AND "correlation"—to generate the broadest range of results for subsequent screening. We restricted the searches to research outputs (e.g., articles and dissertations) presented in English and that appeared from January 1981 to June 2023. The choice of the start date considered Scott et al.'s (2021) note on the history of bilingual deaf education research that 'it was not until the 1980s that research began to appear in academic journals describing the use of ASL, and thus bilingualism, in deaf education' (p. 50). To supplement the database searches, we also checked the articles published in six major journals, including *Journal of Deaf Studies and Deaf Education*; *American Annals of the Deaf*; *Deafness & Education International*; *Sign Language Studies*; *Language, Speech & Hearing Services in Schools*; and *Journal of Speech, Language, and Hearing Research*. Studies cited in major integrated or systematic reviews (e.g., Cummins, 2007; Paul & Yan, 2023; Swanwick, 2016) were also checked. These searches were further supplemented by searching Google Scholar.

The outputs with duplicates removed were first screened by checking the title and the abstract to exclude those that did not show any immediate focus on the issue of the present review. Outputs such as literature reviews, book reviews and editorials were also excluded. Those that had remained were reviewed in detail against a set of inclusion and exclusion criteria. Specifically, an output must include direct measures for both sign language and spoken/written language and report at least one cross-linguistic correlation. Those outputs where cross-linguistic relationships were tested but correlations not reported were excluded. Finally, psycholinguistic experiments were excluded where the (negative) correlations involved response latency measures. This review was eventually based on 52 outputs that involved a total of 70 independent samples ($N = 3570$). Figure 1 shows the literature search and screening process.

Coding procedure

Different from some meta-analytic studies where the goal was either to code the correlates of a particular 'target' variable such as L2 reading comprehension (e.g., Jeon & Yamashita, 2022) or to pair up corresponding skills in L1 and L2 (e.g., Yang et al., 2017), we took an open and inclusive approach to code all cross-linguistic correlations reported between sign language and spoken/written language measures in the included outputs (see Appendix S1 for the competences we eventually coded for correlations). A debate related to sign language and bilingual deaf education is whether Manually Coded Speech (MCS) (e.g., Manually Coded English or MCE) and signing systems may have a legitimate role (e.g., Mayer, 2009; Paul & Yan, 2023; Scott & Henner, 2021). The present review excluded correlations involving competences of signing systems, because these competences are essentially not *sign language* based. It nonetheless coded correlations involving MCS measures

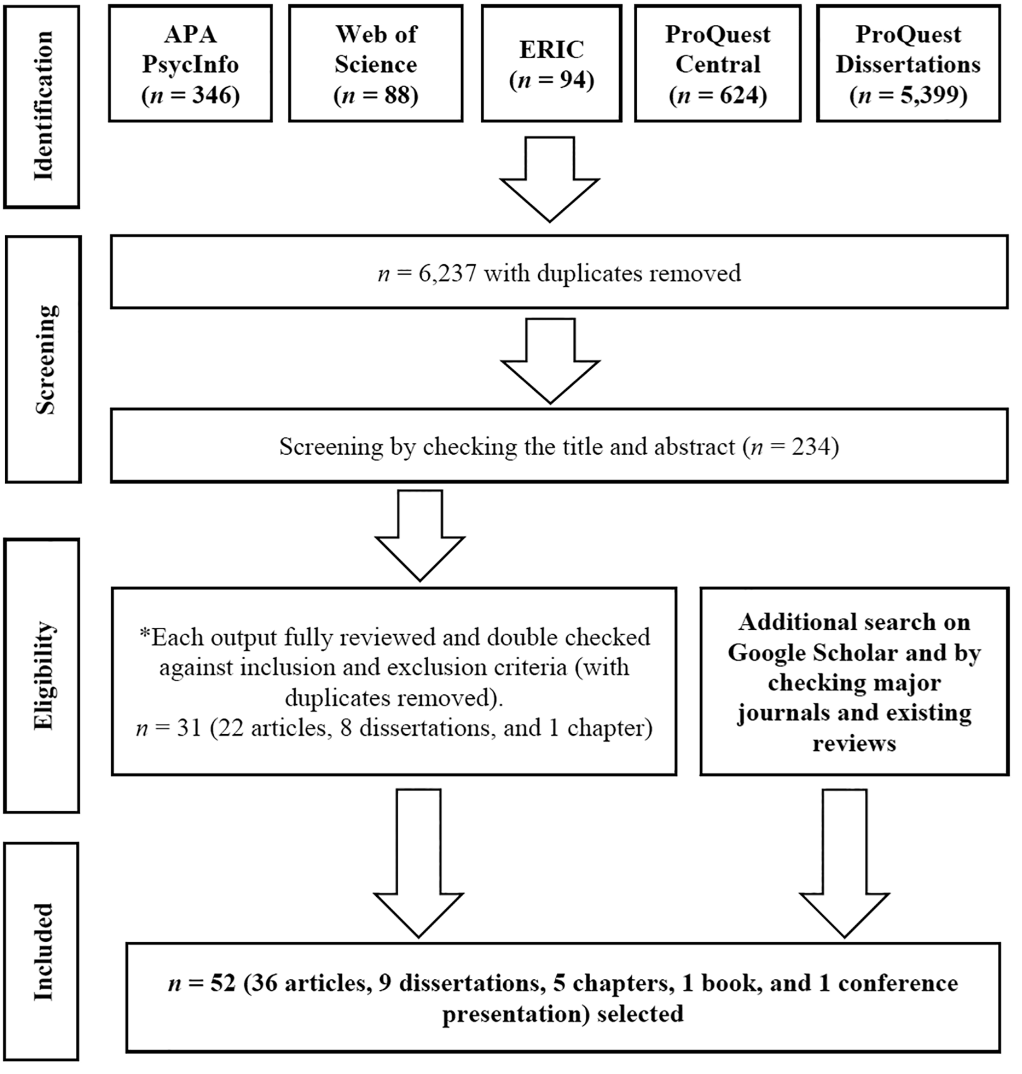

FIGURE 1 A flow chart showing the process of literature search, screening, and study selection. *A small number of outputs of different types were duplicates and hence removed. For example, Scott and Hoffmeister (2017) was based on the first author's dissertation. Only the former was included. *n* indicates the number of outputs.

because they did involve sign language vocabulary. MCS was coded as a correlate in separation from other variables that were clearly sign language based such as fingerspelling, PA, and lexico-semantic knowledge. Table S1 (available on the website of *Review of Education* and also on https://osf.io/5pnce) presents a list of the included studies; the correlations and the moderators coded for each study (see below); as well as some study features such as the study context, the sign language and spoken/written language, and sample size.

Coding correlations

The coding of correlations was characterised by both inductive and deductive strategies. Existing studies, especially meta-analytic studies (e.g., Ke et al., 2023; Melby-Lervåg &

Lervåg, 2011), have shown a set of important correlates that would deserve special coding attention, such as metalinguistic awareness, vocabulary knowledge, grammatical knowledge, word decoding, oral language, listening comprehension and reading comprehension. Apparently, not all of these correlates (e.g., L1–L2 decoding) pertain to signing bilingual learners. Conversely, some important skills pertain to d/Deaf children only, a notable example being fingerspelling. The coding of correlations consequently involved iterative processes. It began with initial 'open' coding of all cross-linguistic correlations as reported in primary studies; followed by efforts to combine competences, if necessary, under the guidance of those reported in the meta-analytic literature; and further attention to measured competences unique to signing bilinguals.

The cross-linguistic correlations extracted from the 70 primary studies eventually involved seven sign language competences and eight spoken/written language competences. The definition of each competence is presented and illustrated with task examples in Appendix S1 available on https://osf.io/5pnce. The sign language correlates included PA, fingerspelling, lexico-semantic knowledge, morpho-syntactic/grammatical knowledge, sign language comprehension, sign language production and general sign language proficiency. MCS, for the reason explained earlier, was also included as a correlate. The spoken/written language correlates included PA, word reading, lexico-semantic knowledge, morpho-syntactic/grammatical knowledge, reading comprehension, spoken/written language production and general spoken/written language proficiency. If more than one correlation was reported on a cross-linguistic relationship, we calculated the average. For longitudinal studies, we extracted the correlations based on the first wave of data unless the competences measured for that wave did not involve cross-linguistic correlations. A few studies reported both zero-order and partial correlations rather than just the former as in most other studies. To be consistent, we coded zero-order correlations unless the study only reported partial correlations.

Coding moderators

Moderator analysis can generate important insights into the conditioning of 'interdependence' or transfer, which has both theoretical significance and implications for practice (e.g., instructional differentiation). For the present meta-analysis, the following moderators were coded, with references to previous meta-analyses of cross-linguistic correlation coefficients on the one hand (e.g., Ke et al., 2023; Melby-Lervåg & Lervåg, 2011; Prevoo et al., 2016) and those of d/Deaf learners on the other (e.g., Zhang et al., 2023).

Spoken/written language

Spoken/written language was coded as either alphabetic (e.g., English, Dutch, Swedish, French) or non-alphabetic (e.g., Chinese, Japanese).

Age/grade

Participants were coded as elementary (grade 5 or lower; or age 11 or younger); secondary (grades 6 to 12; or age 12 to 18); or university/adult. If a study involved participants across the age/grade ranges, we referred to the majority group (defined as larger than 50% of the overall sample) and then coded the sample accordingly.

Degree of hearing level (HL)

Degree of HL was coded into two ordinal categories based on the Pure-Tone Average reported on the better unaided ear for the participants: moderate to moderately severe (41 dB to 70 dB) and severe to profound (71 dB and above). If a study involved participants with a range of degrees of HL, we referred to the majority group (over 50% of the sample) and coded the sample accordingly.

School/programme type

School/programme was coded as one of two types. ‘Bilingual’ refers to sign language having a prominent role in instruction and communication in the school or programme, particularly where sign language is used as the medium of instruction. Schools/programmes described to follow a Total Communication (TC) philosophy or adopt Simultaneous Communication (SimCom) were coded as TC/SimCom.

Signer status

Native and non-native signers are defined as deaf children of deaf parents (DCDP) and deaf children of hearing parents (DCHP), respectively. We coded ‘signer status’ as one of three groups: native (all participants in the sample were DCDP; or the ratio of DCDP to DCHP was greater than 2); non-native (all participants in the sample were DCHP; or the ratio of DCHP to DCDP was greater than 2); or balanced (the ratio was smaller than 2).

First exposure to sign language

A range of cut-off age points (e.g., 2, 3, 5, 6, 7 and 8) was adopted in the included studies. To be consistent in coding across studies, we defined early and late signers, respectively, as those who were first exposed to sign language before and after age 3. First exposure to sign language can be both related to and distinct from signer status as defined above. While DCDP could all be early signers, DCHP may be either early or late signers.

Language preference

Participants' language preference was coded as sign language, spoken language (including SimCom/MCS) or both sign language and spoken language. Sign language proficiency was not coded, because, on the one hand, it was rarely measured, and on the other hand, not using a standardised measure also meant the proficiency could not be codable in any absolute terms to enable comparisons across primary studies.

Sign language comprehension task

Sign language comprehension was coded as passage comprehension, sentence comprehension or mixed, based on the task focus.

Reading comprehension task

Reading comprehension was also coded as passage, sentence or mixed.

Output type

Journal articles, book chapters and the book were coded as published whereas doctoral dissertations and the conference presentation were coded as unpublished.

Following Prevoo et al. (2016), we did not exclude primary studies where a moderator could not be coded but instead classified them as 'uncodable'. Excluding those studies (significant in number for some moderators; see Tables S1 and S2) would result in a loss of opportunity to further understand study heterogeneities, such as how the correlations in 'uncodable' studies might or might not differ in magnitude from those coded studies.

Reliability of coding

The first two authors first independently coded about 30% of the outputs, which included the book, the conference presentation, and a random sample for each of the other three output types, that is, two chapters, three dissertations and ten articles. The 17 outputs involved 22 independent samples. The two coders showed 100% agreement on all moderators except age/grade ($k=2$), degrees of HL ($k=1$), first exposure to sign language ($k=2$), sign language comprehension type ($k=1$) (k indicates the number of independent samples where a disagreement was found; the rate of difference for all these moderators was lower than 10%). They coded a total of 57 effect sizes or cross-linguistic correlations. There were eight effect sizes (about 14%) where the coding result showed a difference. Cohen's kappa (κ) was 0.856 ($p<0.001$), suggesting a very high coding agreement. The two coders subsequently met to discuss the coding results and resolved the differences. The other authors were also consulted for a few cases. After the initial coding, the first author proceeded to code the rest of the studies. Coding results for all the studies can be found in Table S1 online.

Meta-analysis procedure

All meta-analyses were conducted with the Comprehensive Meta-Analysis (CMA 3.0) program (Borenstein, 2022). A cross-linguistic relationship was meta-analysed only if there were three or more effect sizes. Random-effects models were applied to estimate mean correlations. Different from a fixed-effects model, a random-effects model assumes that study variations are systematic rather than due to sampling error. Cohen's (1988, 1992) general guideline—that is, 0.10, 0.30 and 0.50 indicate a small, medium and large effect, respectively—was followed for interpreting the magnitude of correlations.

A Q test was also conducted on study heterogeneity for each cross-linguistic relationship (Hedges & Olkin, 2014). I^2 was also reported, which refers to the percentage of the variability among effect sizes for a cross-linguistic relationship that is caused by real heterogeneity rather than by sampling error. There are no agreed cut-off values of I^2 for interpreting the actual size of heterogeneity. Based on Higgins et al. (2003), a general guideline is that 25%, 50% and 75% represent a small, moderate and high level of heterogeneity, respectively.

Moderator analysis was only conducted for a cross-linguistic relationship where significant heterogeneity was found; there were six or more effect sizes; and each subsample must also include at least two effect sizes. A Q test, which is like an F test in the analysis of variance, was conducted to estimate the degree of difference between the subsamples of effect sizes defined by the moderator. A significant Q test result means that there is a statistically significant effect of a moderator, or in other words, a significant between-group difference in the magnitude of the correlations for that moderator. Primary studies that did not allow for the coding of a moderator (i.e., 'uncodable') were included for moderator analysis as long as other conditions were met. In addition to moderator analysis on output type, we also checked whether retrieval bias was present for each relationship through visually inspecting a funnel plot. A plot, in the absence of retrieval bias, should be expected to display the effect sizes in the form of an inverted funnel and with no effect sizes missing on either side of the mean. The funnel plots presented in Appendix S3 (https://osf.io/5pnce) seem to suggest a lack of notable retrieval bias for any relationships.

REVIEW AND META-ANALYTIC FINDINGS

Review findings

Table S2 presents a description of the basic study features coded of the 70 independent samples. Further details can be found in Table S1 (available on https://osf.io/5pnce). The studies were conducted in 14 countries/regions of the world, but mostly in the United States ($k=45$). The cross-linguistic correlations involved 14 sign languages and eight spoken/written languages. A large majority focused on ASL ($k=48$) and English ($k=54$); and on school-aged students ($k=51$). The number of studies, based on the year of reporting, suggested increasing interests in cross-linguistic correlations between sign language and spoken/written language over the past decades. While only 10 studies were reported over the 20 years from 1981 to 2000, 60 appeared in the twenty-first century ($k=18$ from 2001 to 2010; $k=32$ from 2011 to 2020; $k=10$ from 2021 to 2023).

Table S3 presents the number of effect sizes for each cross-linguistic relationship. A total of 202 cross-linguistic correlations were coded. Some relationships obviously received more research attention than others. The greatest number of effect sizes ($k=22$) focused on the correlation between sign language comprehension and reading comprehension. There were five other relationships where there were 10 or more effect sizes, such as fingerspelling and reading comprehension ($k=15$) and sign language lexico-semantic knowledge and reading comprehension ($k=14$). There were seven cross-linguistic relationships where there were five to nine effect sizes, such as fingerspelling and word reading ($k=8$). For all other relationships, the number of effect sizes was very small ($k=4$ or less); no correlations were reported for a small number of cross-linguistic relationships. Reading comprehension was the spoken/written language competence that received the greatest attention with a total of 75 effect sizes that involved all seven sign language correlates. Fingerspelling and morpho-syntactic/grammatical knowledge were the sign language competences that received the greatest attention ($k=39$ for each). Language production overall received minimal attention for both sign language and spoken/written language.

Correlation and heterogeneity estimates

Table 1 presents the mean correlation estimates and the heterogeneity test results for all the cross-linguistic relationships with three or more effect sizes. To organise the presentation on the meta-analytic findings, in what follows we preliminarily group the relationships into four major categories based on whether the competences in question were lower- or higher-level processes (see Jeon & Yamashita, 2022). Higher-level processes are defined

TABLE 1 Summary of number of effect sizes, mean correlations, and study heterogeneity.

	SpL PA	SpL WR	SpL LSK	SpL GK	SpL RC	SpL Prod	SpL Gen
Sign PA	$k=3$	$k=3$	$k=2$		$k=3$		$k=4$
	$r=0.462$ [0.029, 0.749]	$r=0.402$ [0.173, 0.590]			$r=0.322$ [0.131, 0.490]		$r=0.365$ [0.156, 0.542]
	$Z=2.082$, $p=0.037$	$Z=3.318$, $p=0.001$			$Z=3.233$, $p=0.001$		$Z=3.335$, $p<0.001$
	$Q=7.302$, $p=0.026$	$Q=3.278$, $p=0.194$			$Q=2.805$, $p=0.246$		$Q=1.950$, $p=0.583$
	$I^2=72.611$; $\tau^2=0.123$	$I^2=38.982$; $\tau^2=0.019$			$I^2=28.706$; $\tau^2=0.009$		$I^2=0.000$; $\tau^2=0.000$
Sign FS	$k=4$	**$k=8$**	**$k=6$**	$k=3$	**$k=15$**	$k=1$	$k=2$
	$r=0.553$ [0.436, 0.652]	**$r=0.645$ [0.509, 0.749]**	**$r=0.467$ [0.227, 0.653]**	$r=0.602$ [0.423, 0.736]	**$r=0.622$ [0.529, 0.699]**		
	$Z=7.867$, $p<0.001$	**$Z=7.322$, $p<0.001$**	**$Z=3.606$, $p<0.001$**	$Z=5.563$, $p<0.001$	**$Z=10.308$, $p<0.001$**		
	$Q=4.980$, $p=0.173$	**$Q=40.463$, $p<0.001$**	**$Q=24.719$, $p<0.001$**	$Q=6.871$, $p=0.032$	**$Q=41.827$, $p<0.001$**		
	$I^2=39.756$; $\tau^2=0.010$	**$I^2=82.700$; $\tau^2=0.064$**	**$I^2=79.773$; $\tau^2=0.091$**	$I^2=70.893$; $\tau^2=0.032$	**$I^2=66.529$; $\tau^2=0.045$**		
Sign LSK	$k=2$	$k=3$	**$k=9$**	$k=4$	**$k=14$**	$k=1$	$k=1$
		$r=0.512$ [0.079, 0.783]	**$r=0.446$ [0.307, 0.566]**	$r=0.568$ [0.206, 0.793]	**$r=0.517$ [0.402, 0.617]**		
		$Z=2.277$, $p=0.023$	**$Z=5.782$, $p<0.001$**	$Z=2.904$, $p=0.004$	**$Z=7.625$, $p<0.001$**		
		$Q=32.107$, $p<0.001$	**$Q=28.476$, $p<0.001$**	$Q=51.052$, $p<0.001$	**$Q=66.937$, $p<0.001$**		
		$I^2=93.771$; $\tau^2=0.173$	**$I^2=71.906$; $\tau^2=0.042$**	$I^2=94.124$; $\tau^2=0.174$	**$I^2=80.579$; $\tau^2=0.060$**		
Sign GK	$k=3$	$k=5$	$k=4$	**$k=10$**	**$k=12$**	$k=1$	$k=4$
	$r=0.370$ [0.256, 0.474]	$r=0.621$ [0.562, 0.674]	$r=0.430$ [0.257, 0.577]	**$r=0.471$ [0.276, 0.628]**	**$r=0.512$ [0.377, 0.626]**		$r=0.331$ [0.053, 0.562]
	$Z=6.009$, $p<0.001$	$Z=15.576$, $p<0.001$	$Z=4.558$, $p<0.001$	**$Z=4.405$, $p<0.001$**	**$Z=6.540$, $p<0.001$**		$Z=2.321$, $p=0.020$
	$Q=0.945$, $p=0.623$	$Q=4.608$, $p=0.330$	$Q=2.639$, $p=0.451$	**$Q=67.862$, $p<0.001$**	**$Q=45.734$, $p<0.001$**		$Q=4.158$, $p=0.245$
	$I^2=0.000$; $\tau^2=0.000$	$I^2=13.203$; $\tau^2=0.001$	$I^2=0.000$; $\tau^2=0.000$	**$I^2=86.738$; $\tau^2=0.111$**	**$I^2=75.948$; $\tau^2=0.061$**		$I^2=27.851$; $\tau^2=0.025$

(Continues)

TABLE 1 (Continued)

	SpL PA	SpL WR	SpL LSK	SpL GK	SpL RC	SpL Prod	SpL Gen
Sign LC		$k=4$ $r=0.517$ [0.376, 0.636] $Z=6.313$, $p<0.001$ $Q=4.033$, $p=0.258$ $I^2=25.604$; $\tau^2=0.009$	$k=6$ $r=0.441$ [0.276, 0.581] $Z=4.888$, $p<0.001$ $Q=10.785$, $p=0.056$ $I^2=53.640$; $\tau^2=0.028$	$k=3$ $r=0.586$ [0.159, 0.828] $Z=2.577$, $p=0.010$ $Q=13.104$, $p=0.001$ $I^2=84.737$; $\tau^2=0.166$	**$k=22$** **$r=0.517$ [0.427, 0.597]** **$Z=9.665$, $p<0.001$** **$Q=78.025$, $p<0.001$** **$I^2=73.086$; $\tau^2=0.051$**	$k=1$	$k=2$
Sign Prod		$k=1$				$k=1$	$k=2$
Sign Gen		$k=2$	$k=2$	$k=1$	$k=4$ $r=0.625$ [0.517, 0.714] $Z=8.921$, $p<0.001$ $Q=6.182$, $p=0.103$ $I^2=51.465$; $\tau^2=0.014$		$k=12$ $r=0.427$ [0.345, 0.502] $Z=9.318$, $p<0.001$ $Q=12.202$, $p=0.349$ $I^2=9.853$; $\tau^2=0.003$
Sign MCS		$k=2$	$k=2$	$k=1$	$k=5$ $r=0.566$ [0.469, 0.650] $Z=9.429$, $p<0.001$ $Q=4.024$, $p=0.403$ $I^2=0.588$; $\tau^2=0.000$		$k=2$

Note: Bolded sections are the cross-linguistic correlations where moderator analysis was conducted because (1) the study heterogeneity (Q test result) was significant; and (2) $k\geq6$. A Q test was not conducted with mean r estimated if $k<3$.

Abbreviations: FS, fingerspelling; Gen, general proficiency; GK, morpho-syntactic/grammatical knowledge; LC, language comprehension; LSK, lexico-semantic knowledge; MCS, manually coded speech; PA, phonological awareness; Prod, language production; RC, reading comprehension; Sign, sign language; SpL, spoken language; WR, word reading.

to include language (reading) comprehension, language production and general proficiency in either language. All other processes are considered lower-level processes. Because of space limit, the following presentation prioritises those relationships where significant study heterogeneity was found and subsequent moderate analysis was performed (for other relationships, refer to Table 1).

Lower processes in sign language with lower processes in spoken/written language

A total of 69 effect sizes focused on cross-linguistic relationships involving lower processes in sign language and those in spoken/written language.

Fingerspelling and word reading

Eight effect sizes ($N=687$) were meta-analysed on the relationship between fingerspelling and word reading. As shown in Table 1, the weighted mean correlation was significant, $r=0.645$ (95% CI: 0.509, 0.749), $z=7.322$, $p<0.001$. It showed a large effect (Cohen, 1988, 1992). The variation in the eight effect sizes was significant, $Q=40.463$, $p<0.001$; and $I^2=82.870\%$, which indicates a high level of variability (Higgins et al., 2003). Appendix S2 presents the Forest plot for this relationship as well as all others.

Table 2 further shows the results of the analyses for the moderators that met the criteria set for this review. None of the moderators showed a significant effect. Specifically, the correlation did not significantly differ between elementary school ($r=0.675$) and university/adult students ($r=0.525$). There was no significant difference between the subsamples where participants' degree of HL was uncodable ($r=0.760$) and where participants were severely or profoundly deaf ($r=0.585$). The correlation for participants in bilingual programmes ($r=0.606$) did not differ significantly from that for those participating in studies where programme type was uncodable ($r=0.673$). The correlation, likewise, did not differ significantly between non-native signers ($r=0.719$) and the 'balanced' group ($r=0.624$). Finally, no significant difference was found, either, between those studies where participants' language preference was uncodable ($r=0.638$) and those where participants had sign language as the preferred language ($r=0.651$). An assessment of the magnitude of the correlations themselves, however, showed notably that the correlations across all subsamples were large in magnitude for all moderators, which seems to suggest a very robust influence of fingerspelling ability on word reading development.

Fingerspelling and lexico-semantic knowledge

Six effect sizes ($N=291$) were meta-analysed on the relationship between fingerspelling and lexico-semantic knowledge in spoken/written language. The weighted mean correlation was significant, $r=0.467$ (95% CI: 0.227, 0.653), $z=3.606$, $p<0.001$. It showed a medium effect. The study heterogeneity was significant—$Q=24.719$, $p<0.001$; and $I^2=79.773\%$—which indicates a high level of variability.

Table 3 further shows the results of the analyses for some moderators, none of which showed a significant effect except output type. Specifically, the correlation did not significantly differ between elementary school ($r=0.485$) and university/adult students ($r=0.442$). The correlation showed no significant significance between studies focused on non-native signers ($r=0.405$) and those where there was a balanced representation of native and non-native signers ($r=0.443$). There was no significant difference in the correlation between studies focused on early signers ($r=0.464$) and those where students' first exposure to sign language was uncodable ($r=0.474$). Likewise, no significant difference was found between those studies where participants' language preference was uncodable ($r=0.484$) and sign

TABLE 2 Moderator analysis results for the relationship between fingerspelling and word reading ($k=8$).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Age/grade	Elementary	6	0.675	0.520, 0.787	6.613 (<0.001)	0.842 (0.359)
	Secondary	0	–	–	–	
	University/adult	2	0.525	0.142, 0.772	2.593 (<0.001)	
	Uncodable	0	–	–	–	
Degree of hearing level	Mild to moderately severe	0	–	–	–	3.126 (0.077)
	Severe to profound	6	0.585	0.435, 0.703	6.458 (<0.001)	
	Uncodable	2	0.760	0.602, 0.860	6.528 (<0.001)	
School or programme type	Bilingual	4	0.606	0.361, 0.772	4.250 (<0.001)	0.259 (0.611)
	TC/SimCom	0	–	–	–	
	Uncodable	4	0.673	0.476, 0.805	5.373 (<0.001)	
Signer status	Native	0	–	–	–	0.491 (0.483)
	Non-native	3	0.719	0.478, 0.860	4.596 (<0.001)	
	Balanced	4	0.624	0.405, 0.775	4.762 (<0.001)	
	Uncodable	1	–	–	–	
Language Preference	Sign language	3	0.651	0.394, 0.813	4.230 (<0.001)	0.009 (0.926)
	Spoken panguage	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	5	0.638	0.439, 0.777	5.220 (<0.001)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

language ($r=0.442$). All the correlations were medium in magnitude for the subsamples of these moderators.

Lexico-semantic knowledge

Nine effect sizes ($N=491$) were meta-analysed on the relationship between lexico-semantic knowledge in sign language and spoken/written language. The weighted mean correlation was significant, $r=0.446$ (95% CI: 0.307, 0.566), $z=5.782$, $p<0.001$. It showed a medium effect. The variation in the effect sizes was significant—$Q=28.476$, $p<0.001$; and $I^2=71.906\%$—which indicates a moderate level of variability.

Table 4 further shows the results of the analyses for four moderators, none of which showed a significant effect. Specifically, the correlation did not differ significantly between elementary school ($r=0.418$; medium), secondary school ($r=0.580$; large) and adults/university students ($r=0.394$; medium). There was no significant difference between non-native signers ($r=0.381$; medium) and the 'balanced' group ($r=0.600$; large); and between studies focused on early signers ($r=0.461$), later signers ($r=0.500$) and those where students' first exposure to sign language was uncodable ($r=0.413$). It is interesting that the correlation was a large effect for late signers, which may suggest even greater importance of sign language basis for those students' spoken/written language lexico-semantic development. Finally, the correlation did not differ significantly between those studies where language preference was uncodable ($r=0.391$; medium) and those where sign language was the preferred language ($r=0.514$; large).

TABLE 3 Moderator analysis results for the relationship between fingerspelling and lexico-semantic knowledge (k=6).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Age/grade	Elementary	4	0.484	0.132, 0.727	2.622 (0.009)	0.025 (0.873)
	Secondary	0	–	–	–	
	University/adult	2	0.442	−0.053, 0.762	1.764 (0.078)	
	Uncodable	0	–	–	–	
Signer status	Native	1	–	–	–	0.017 (0.897)
	Non-native	2	0.405	−0.093, 0.741	1.610 (0.107)	
	Balanced	2	0.443	0.006, 0.738	1.983 (0.047)	
	Uncodable	1	–	–	–	
Exposure to sign language	Early	3	0.464	0.068, 0.733	2.269 (0.023)	0.002 (0.968)
	Late	0	–	–	–	
	Uncodable	3	0.474	0.069, 0.744	2.267 (0.023)	
Language preference	Sign language	2	0.442	−0.053, 0.762	1.764 (0.078)	0.025 (0.873)
	Spoken language	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	4	0.484	0.132, 0.727	2.622 (0.009)	
Output type	Published	4	0.322	0.094, 0.517	2.735 (0.006)	6.828 (0.009)
	Unpublished	2	0.740	0.504, 0.873	4.703 (<0.001)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

Morpho-syntactic/grammatical knowledge

Ten effect sizes (N=651) were meta-analysed on the relationship between morpho-syntactic/grammatical knowledge in sign language and spoken/written language. The weighted mean correlation was significant—r=0.471 (95% CI: 0.276, 0.628), z=4.405, p<0.001. It showed a medium effect. Study variation was significant—Q=67.862, p<0.001; and I^2=86.738%—which indicates a high level of variability.

Table 5 further shows the results of the analyses for six moderators, none of which had a significant effect except degree of HL. Specifically, the correlation did not differ significantly between elementary school (r=0.468), secondary school (r=0.271) and the uncodable group (r=0.684). If the uncodable group was excluded from the comparison, however, the correlation was significantly stronger among elementary school students. The correlation was significantly stronger in participants whose degree of HL was uncodable (r=0.660; large) than in those who were severely or profoundly deaf (r=0.314; medium). Students in bilingual programmes (r=0.462) did not show any significant difference from those in programmes characterised by SimCom or TC (r=0.235). It is worth noting, however, that the former subsample showed a medium effect, whereas the effect was small in the latter subsample. There was no significant difference between those studies where participants' language preference was uncodable (r=0.454; medium) and sign language (r=0.530; large). Finally, no significant difference was found for the correlation between published (r=0.398; medium) and unpublished studies (r=0.633; large).

TABLE 4 Moderator analysis results for the relationship between sign language and spoken language lexico-semantic knowledge ($k=9$).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Age/grade	Elementary	5	0.418	0.231, 0.576	4.144 (<0.001)	1.118 (0.572)
	Secondary	2	0.580	0.275, 0.779	3.418 (0.001)	
	University/adult	2	0.394	0.068, 0.644	2.341 (0.019)	
	Uncodable	0	–	–	–	
Signer status	Native	0	–	–	–	2.520 (0.112)
	Non-native	6	0.381	0.203, 0.535	4.019 (<0.001)	
	Balanced	2	0.600	0.372, 0.760	4.488 (<0.001)	
	Uncodable	1	–	–	–	
Exposure to sign language	Early	2	0.461	0.138, 0.695	2.717 (0.007)	0.252 (0.882)
	Late	2	0.500	0.171, 0.729	2.857 (0.004)	
	Uncodable	5	0.413	0.195, 0.591	3.570 (<0.001)	
Language preference	Sign language	2	0.514	0.212, 0.727	3.151 (0.002)	0.534 (0.465)
	Speech	1	–	–	–	
	Both	0	–	–	–	
	Uncodable	6	0.391	0.190, 0.560	3.671 (<0.001)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

Lower processes in sign language with higher processes in spoken/written language

A total of 58 effect sizes focused on cross-linguistic relationships involving lower processes in sign language and higher processes in spoken/written language.

Fingerspelling and reading comprehension

Fifteen effect sizes ($N=728$) were meta-analysed on the relationship between fingerspelling and reading comprehension. This was one of the two high-evidence (defined as $k \geq 15$ in Jeon & Yamashita, 2022) relationships as shown in Table 1. The weighted mean correlation was significant—$r=0.622$ (95% CI: 0.529, 0.699), $z=10.308$, $p<0.001$. It showed a large effect. The variation in the effect sizes was significant—$Q=41.827$, $p<0.001$; and $I^2=66.529\%$—which indicates a moderate level of variability.

Table 6 further shows the results of the analyses for eight moderators. The correlation for elementary school students ($r=0.698$) was significantly stronger than that for university/adult students ($r=0.509$). None of the other moderators showed any significant effect. Specifically, there was no significant difference between those studies where participants' degree of HL was uncodable ($r=0.696$) and those where participants were severely or profoundly deaf ($r=0.603$). Students studying in bilingual programmes ($r=0.675$) did not show any significant difference from those in the uncodable group ($r=0.575$). The correlation, likewise, did not differ significantly between native signers ($r=0.629$), non-native signers ($r=0.689$) and the 'balanced' subsample ($r=0.558$). The correlation for early signers ($r=0.551$) did not differ significantly from those in studies where signer status could not be coded ($r=0.664$). Likewise, there was no significant difference between those studies where participants' language preference was uncodable ($r=0.689$) and sign language ($r=0.543$). The correlation did not differ significantly, either, between tasks focused on passage comprehension

TABLE 5 Moderator analysis results for the relationship between sign language and spoken language morpho-syntactic/grammatical knowledge ($k = 10$).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Age/grade	Elementary	5	0.468	0.236, 0.650	3.724 (<0.001)	3.931 (0.140)
	Secondary	3	0.271	−0.086, 0.566	1.497 (0.134)	
	University/adult	0	–	–	–	
	Uncodable	2	0.684	0.398, 0.849	3.941 (<0.001)	
Degree of hearing level	Mild to moderately severe	1	–	–	–	10.296 (0.001)
	Severe to profound	5	0.314	0.110, 0.493	2.963 (0.003)	
	Uncodable	4	0.660	0.540, 0.754	8.237 (<0.001)	
School or programme type	Bilingual	6	0.462	0.236, 0.641	3.782 (<0.001)	2.712 (0.258)
	TC/SimCom	2	0.235	−0.223, 0.608	1.007 (0.314)	
	Uncodable	2	0.641	0.335, 0.824	3.618 (<0.001)	
Signer status	Native	0	–	–	–	3.100 (0.078)
	Non-native	7	0.699	0.449, 0.848	4.435 (<0.001)	
	Balanced	2	0.436	0.237, 0.600	4.061 (<0.001)	
	Uncodable	1	–	–	–	
Language preference	Sign language	2	0.530	0.069, 0.805	2.218 (0.027)	0.114 (0.735)
	Spoken language	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	8	0.454	0.217, 0.640	3.566 (<0.001)	
Output type	Published	7	0.398	0.159, 0.592	3.171 (0.002)	1.675 (0.196)
	Unpublished	3	0.633	0.316, 0.823	3.484 (<0.001)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

($r = 0.690$) and sentence comprehension ($r = 0.543$). Finally, there was no significant difference between published ($r = 0.590$) and unpublished studies ($r = 0.775$). It is noteworthy that the correlations in all the subsamples across all moderators (whether or not the effect was significant) showed a large effect, which perhaps suggests a strong and robust transfer facilitation effect of fingerspelling on reading comprehension.

Lexico-semantic knowledge and reading comprehension

Fourteen effect sizes ($N = 1036$) were meta-analysed on the relationship between sign language lexico-semantic knowledge and reading comprehension. The mean correlation was significant—$r = 0.517$ (95% CI: 0.402, 0.617), $z = 7.625$, $p < 0.001$. It showed a large effect. The variation in the effect sizes was significant—$Q = 66.937$, $p < 0.001$; and $I^2 = 80.579\%$—which indicates a high level of variability.

Table 7 further shows the results of the analyses for eight moderators, two of which showed a significant effect. Specifically, the correlation did not differ between alphabetic ($r = 0.532$; large) and non-alphabetic ($r = 0.457$; medium) languages. The correlation did not differ between elementary school ($r = 0.621$; large), secondary school ($r = 0.466$; medium) and university/adult students ($r = 0.476$; medium), either. Nevertheless, the magnitude of the correlations perhaps suggested that sign language lexico-semantic knowledge could have a more salient role in reading comprehension at the elementary school stage. There was no

TABLE 6 Moderator analysis results for the relationship between fingerspelling and reading comprehension ($k=15$).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Age/grade	Elementary	8	0.698	0.602, 0.775	10.073 (<0.001)	5.377 (0.020)
	Secondary	1	–	–	–	
	University/adult	6	0.509	0.354, 0.638	5.723 (<0.001)	
	Uncodable	0	–	–	–	
Degree of hearing level	Mild to moderately severe	0	–	–	–	0.825 (0.364)
	Severe to profound	13	0.603	0.497, 0.690	0.031 (<0.001)	
	Uncodable	2	0.696	0.495, 0.827	5.311 (<0.001)	
School or programme type	Bilingual	7	0.675	0.538, 0.777	7.359 (<0.001)	1.215 (0.270)
	TC/SimCom	0	–	–	–	
	Uncodable	8	0.575	0.432, 0.690	6.552 (<0.001)	
Signer status	Native	4	0.629	0.415, 0.777	4.869 (<0.001)	1.322 (0.516)
	Non-native	6	0.689	0.537, 0.798	6.734 (<0.001)	
	Balanced	4	0.558	0.341, 0.719	4.491 (<0.001)	
	Uncodable	1	–	–	–	
Exposure to sign language	Early	6	0.551	0.385, 0.683	5.677 (<0.001)	1.534 (0.216)
	Late	1	–	–	–	
	Uncodable	8	0.664	0.546, 0.756	8.395 (<0.001)	
Language preference	Sign language	7	0.543	0.389, 0.667	6.025 (<0.001)	2.803 (0.094)
	Spoken language	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	8	0.689	0.571, 0.779	8.427 (<0.001)	
RC task	Passage	7	0.690	0.573, 0.779	8.503 (<0.001)	2.621 (0.105)
	Sentence	7	0.543	0.376, 0.676	5.599 (<0.001)	
	Both	1	–	–	–	
Output type	Published	12	0.590	0.491, 0.673	9.529 (<0.001)	3.518 (0.061)
	Unpublished	3	0.775	0.597, 0.880	5.875 (<0.001)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

significant difference between those studies where participants' degree of HL was uncodable ($r=0.610$; large) and those where participants were severely or profoundly deaf ($r=0.521$; large). Students studying in bilingual programmes ($r=0.505$; large) showed a significantly stronger correlation than those in programs characterised by TC/SimCom ($r=0.175$; small and non-significant). Further, signer status showed a significant moderation effect. The correlation was significantly stronger in non-native signers ($r=0.549$; large) and the 'balanced' subsample ($r=0.586$; large) than in the uncodable subsample ($r=0.193$; small and non-significant). The former two groups, however, did not show a significant difference. The correlation did not differ between early signers ($r=0.580$; large), late signers ($r=0.538$; large) and those in uncodable studies ($r=0.478$; medium). There was no significant difference between those studies where participants' language preference was uncodable ($r=0.481$;

TABLE 7 Moderator analysis results for the relationship between sign language lexico-semantic knowledge and reading comprehension ($k=14$).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Spoken language	Alphabetic	11	0.532	0.412, 0.635	7.473 (<0.001)	0.335 (0.563)
	Non-alphabetic	3	0.457	0.193, 0.660	3.242 (0.001)	
Age/grade	Elementary	4	0.621	0.435, 0.755	5.489 (<0.001)	1.905 (0.386)
	Secondary	7	0.466	0.298, 0.607	4.987 (<0.001)	
	University/adult	3	0.476	0.211, 0.676	3.346 (0.001)	
	Uncodable	0	–	–	–	
Degree of hearing level	Mild to moderately severe	1	–	–	–	1.469 (0.226)
	Severe to profound	9	0.521	0.420, 0.609	8.736 (<0.001)	
	Uncodable	4	0.610	0.493, 0.705	8.247 (<0.001)	
School or programme type	Bilingual	4	0.505	0.352, 0.632	5.787 (<0.001)	8.214 (0.016)
	TC/SimCom	2	0.175	−0.125, 0.446	1.145 (0.252)	
	Uncodable	8	0.581	0.480, 0.667	9.237 (<0.001)	
Signer status	Native	1	–	–	–	9.256 (0.010)
	Non-native	8	0.549	0.437, 0.645	8.114 (<0.001)	
	Balanced	3	0.586	0.436, 0.705	6.433 (<0.001)	
	Uncodable	2	0.193	−0.065, 0.426	1.470 (0.142)	
Exposure to sign language	Early	3	0.580	0.317, 0.760	3.887 (<0.001)	0.535 (0.765)
	Late	4	0.538	0.295, 0.716	3.967 (<0.001)	
	Uncodable	7	0.478	0.295, 0.627	4.712 (<0.001)	
Language preference	Sign language	4	0.588	0.401, 0.728	5.288 (<0.001)	0.939 (0.332)
	Spoken language	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	10	0.481	0.340, 0.602	6.010 (<0.001)	
Output type	Published	12	0.524	0.397, 0.631	7.066 (<0.001)	0.103 (0.749)
	Unpublished	2	0.466	0.059, 0.740	2.220 (0.026)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

medium) and sign language ($r=0.588$; large); and between published ($r=0.524$; large) and unpublished studies ($r=0.466$; medium).

Morpho-syntactic/grammatical knowledge and reading comprehension

Twelve effect sizes ($N=691$) were meta-analysed on the relationship between sign language grammatical/morpho-syntactic knowledge and reading comprehension. The mean correlation was significant—$r=0.512$ (95% CI: 0.377, 0.626), $z=6.540$, $p<0.001$. It showed a large effect. The variation in the effect sizes was significant—$Q=45.734$, $p<0.001$; and $I^2=75.948\%$—which indicates a high level of variability.

Table 8 further shows the results of the analyses for eight moderators. A significant effect was found for two moderators, that is, age/grade and school/programme type. For age/grade, while there was no significant difference between elementary school ($r=0.562$; large) and university/adult students ($r=0.590$; large), for both groups, the correlation was

TABLE 8 Moderator analysis results for the relationship between sign language morpho-syntactic grammatical knowledge and reading comprehension ($k = 12$).

Moderator	Subgroups	k	r	95% CI	Z (p)	Q (p)
Spoken language	Alphabetic	9	0.524	0.369, 0.650	5.869 (<0.001)	0.090 (0.764)
	Non-alphabetic	3	0.482	0.210, 0.684	3.304 (0.001)	
Age/grade	Elementary	7	0.562	0.477, 0.637	10.650 (<0.001)	21.300 (<0.001)
	Secondary	3	0.114	−0.088, 0.307	1.105 (0.269)	
	University/adult	2	0.590	0.445, 0.704	6.697 (<0.001)	
	Uncodable	0	–	–	–	
Degree of hearing level	Mild to moderately severe	1	–	–	–	0.023 (0.880)
	Severe to profound	8	0.563	0.473, 0.641	10.166 (<0.001)	
	Uncodable	3	0.573	0.469, 0.661	8.974 (<0.001)	
School or programme type	Bilingual	3	0.531	0.327, 0.688	4.589 (<0.001)	22.033 (<0.001)
	TC/SimCom	2	0.113	−0.087, 0.304	1.109 (0.267)	
	Uncodable	7	0.577	0.499, 0.645	11.844 (<0.001)	
Signer status	Native	1	–	–	–	1.884 (0.390)
	Non-native	7	0.533	0.374, 0.662	5.780 (<0.001)	
	Balanced	2	0.551	0.303, 0.729	3.951 (<0.001)	
	Uncodable	2	0.331	0.015, 0.587	2.047 (0.041)	
Exposure to sign language	Early	1	–	–	–	0.985 (0.321)
	Late	4	0.578	0.364, 0.733	4.662 (<0.001)	
	Uncodable	7	0.444	0.245, 0.607	4.123 (<0.001)	
Language preference	Sign language	3	0.588	0.287, 0.783	3.483 (<0.001)	0.392 (0.531)
	Spoken language	0	–	–	–	
	Both	1	–	–	–	
	Uncodable	8	0.488	0.300, 0.640	4.672 (<0.001)	
Output type	Published	10	0.520	0.365, 0.648	5.816 (<0.001)	0.074 (0.786)
	Unpublished	2	0.468	0.048, 0.748	2.163 (0.026)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: SimCom, Simultaneous Communication; TC, Total Communication.

higher than that for secondary school students ($r = 0.114$; low and non-significant). For programme type, students studying in bilingual programmes ($r = 0.531$; large) showed a significantly stronger correlation than those studying in TC/SimCom-based programmes ($r = 0.113$; small and non-significant). There was, however, no significant difference between the former group and those in 'uncodable' schools/programmes ($r = 0.577$). None of the six other moderators showed a significant effect. Specifically, the correlation did not differ between alphabetic ($r = 0.524$; large) and non-alphabetic ($r = 0.482$; medium) languages. No significant difference was found between those studies where participants' degree of HL was uncodable ($r = 0.573$; large) and those where participants were severely or profoundly deaf ($r = 0.563$; large). Further, the correlation did not different significantly between non-native signers ($r = 0.533$; large), the 'balanced' subsample ($r = 0.552$; large) and the uncodable subsample ($r = 0.331$; medium). The correlation, likewise, did not differ between late signers (*r* = 0.578; large) and the uncodable subsample (*r* = 0.444; medium). No significant difference was found between those studies where participants' language preference was uncodable (*r* = 0.488; medium) and sign language (*r* = 0.588; large); and between published (*r* = 0.520; large) and unpublished studies (*r* = 0.468; medium).

Higher processes in sign language with lower processes in spoken/written language

A total of 24 effect sizes were reported on cross-linguistic correlations involving higher processes in sign language and lower processes in spoken/written language. Higher sign language processes included language comprehension, language production and general proficiency. In comparison to the other three groups of cross-linguistic relationships, this group was given much less attention in the literature. Three relationships were meta-analysed of sign language comprehension with word reading, lexico-semantic knowledge, and morpho-syntactic/grammatical knowledge in spoken/written language. The results on these relationships can be found in Table 1 and are not presented below because none involved moderator analysis.

Higher processes in sign language with higher processes in spoken/written language

A total of 51 effect sizes focused on cross-linguistic correlations involving higher processes in sign language and those in spoken/written language. In what follows, we only report in detail the correlation between sign language comprehension and reading comprehension. Results on the other cross-linguistic relationships are shown in Table 1 but not presented below because no moderator analysis was further considered.

Sign language comprehension and reading comprehension

Twenty-two effect sizes (*N* = 1290) were meta-analysed on the relationship between sign language comprehension and reading comprehension. This relationship by far received the greatest amount of attention. As shown in Table 1, the mean correlation was significant and showed a large effect—$r = 0.517$ (95% CI: 0.427, 0.597), $z = 9.665$, $p < 0.001$. The variation in the effect sizes was significant—$Q = 78.025$, $p < 0.001$; and $I^2 = 73.086\%$—which indicates a moderate level of variability.

Table 9 further shows the results of the analyses that involved all coded moderators. None of them except output type showed a significant effect. Nevertheless, the magnitude of the correlations for some subsamples demonstrated interesting differences. Specifically, the correlation did not differ between alphabetic (*r* = 0.542; large) and non-alphabetic (*r* = 0.492; medium) languages. Neither did the correlation differ significantly between elementary school (*r* = 0.586; large), secondary school (*r* = 0.483; medium) and university/adult students (*r* = 0.462; medium). The finding that the correlation was a large effect for the elementary group, as opposed to a medium effect in the other two groups, perhaps suggests that sign language comprehension is of particular importance for reading comprehension development in young d/Deaf children. There was no significant difference between studies where participants' degree of HL was uncodable (*r* = 0.430; medium) and those where participants were severely or profoundly deaf (*r* = 0.571; large). The correlation did not differ significantly between students studying in bilingual programmes (*r* = 0.547; large), those in TC/SimCom-based programmes (*r* = 0.470; medium) and those in programmes that could not be coded (*r* = 0.507; large). Further, signer status did not show a significant moderation

TABLE 9 Moderator analysis results for the relationship between sign language comprehension and reading comprehension (k=22).

Moderator	Subgroups	*k*	*r*	95% CI	*Z* (*p*)	*Q* (*p*)
Spoken language	Alphabetic	19	0.522	0.426, 0.606	9.141 (<0.001)	0.062 (0.803)
	Non-alphabetic	3	0.492	0.239, 0.682	3.585 (<0.001)	
Age/grade	Elementary	5	0.586	0.390, 0.731	5.069 (<0.001)	2.787 (0.426)
	Secondary	5	0.483	0.283, 0.642	4.384 (<0.001)	
	University/adult	10	0.462	0.313, 0.589	5.580 (<0.001)	
	Uncodable	2	0.656	0.410, 0.813	4.408 (<0.001)	
Degree of hearing level	Mild to moderately severe	1	–	–	–	2.214 (0.137)
	Severe to profound	16	0.571	0.481, 0.648	10.262 (<0.001)	
	Uncodable	5	0.430	0.241, 0.588	4.206 (<0.001)	
School or programme type	Bilingual	8	0.547	0.403, 0.664	6.460 (<0.001)	0.373 (0.830)
	TC/SimCom	3	0.470	0.194, 0.677	3.190 (0.001)	
	Uncodable	11	0.507	0.374, 0.619	6.644 (<0.001)	
Signer status	Native	2	0.385	0.037, 0.650	2.158 (0.031)	2.591 (0.459)
	Non-native	14	0.540	0.436, 0.630	8.625 (<0.001)	
	Balanced	4	0.568	0.386, 0.708	5.309 (<0.001)	
	Uncodable	2	0.364	0.047, 0.615	2.233 (0.026)	
Exposure to sign language	Early	3	0.436	0.142, 0.660	2.819 (<0.001)	0.482 (0.786)
	Late	8	0.524	0.363, 0.655	5.655 (<0.001)	
	Uncodable	11	0.535	0.398, 0.648	6.684 (<0.001)	
Language preference	Sign language	7	0.536	0.369, 0.669	5.561 (<0.001)	0.083 (0.773)
	Spoken language	0	–	–	–	
	Both	0	–	–	–	
	Uncodable	15	0.508	0.392, 0.608	7.533 (<0.001)	
Sign LC task	Passage	12	0.585	0.486, 0.669	9.412 (<0.001)	2.645 (0.104)
	Sentence	9	0.449	0.298, 0.578	5.391 (<0.001)	
	Mixed	1	–	–	–	
RC task	Passage	17	0.527	0.419, 0.619	8.277 (<0.001)	0.069 (0.792)
	Sentence	4	0.495	0.246, 0.682	3.648 (<0.001)	
	Both	1	–	–	–	
Output type	Published	18	0.473	0.380, 0.556	8.874 (<0.001)	5.342 (0.021)
	Unpublished	4	0.672	0.527, 0.780	6.972 (0.026)	

Note: Heterogeneity results based on subgroups with two or more effect sizes only. Subgroups with no or one effect size were excluded for moderator analysis.

Abbreviations: LC, language comprehension; RC, reading comprehension; SimCom, Simultaneous Communication; TC, Total Communication.

effect. Nevertheless, it is interesting that the correlations for the non-native signer subsample (r=0.540) and the 'balanced' subsample (r=0.568) were a large effect, whereas in the native signer subsample (r=0.385) and the uncodable subsample (r=0.364), the correlation was medium in magnitude. The correlation did not differ between late signers (r=0.524; large), the uncodable subsample (r=0.535; large), and early signers (r=0.436; medium).

No significant difference was found, either, between studies where participants' language preference was uncodable ($r=0.508$; large) and sign language ($r=0.536$; large).

Different from other relationships, we tested a set of additional moderators related to the type of tasks for comprehension in both sign language and spoken/written language. As shown in Table 9, the correlation did not show a significant difference between subsamples with sign language comprehension focused on passage ($r=0.585$) and sentence ($r=0.449$); this was similarly the case for reading comprehension—$r=0.527$ and $r=0.495$ for passage and sentence focus, respectively. It is notable, however, that the correlation at the passage level seemed to consistently show a large effect, whereas the effect at the sentence level was medium.

DISCUSSION

RQ 1 review findings

This review included 52 outputs that reported 202 cross-linguistic correlations based on 70 independent samples of signing bilingual participants. This result indicates a notable interest among sign bilingualism and deaf education researchers in exploring the potential positive, facilitative roles of sign language for the development of spoken language and literacy skills. It is noteworthy that a large majority of the studies ($k=45$ or about 65%) focused on ASL and English in the United States. In most other countries (e.g., the United Kingdom and Sweden), only one or two primary studies met the selection criteria for this review. Much thus remains to be done to expand the literature to more diverse settings and languages (both sign languages and spoken languages) and contribute to discussions and debates on policy and practice concerning the education of d/Deaf children.

There was notably a salient focus on correlating lower processes in sign language with both lower and higher processes in spoken/written language (127 effect sizes or about 63%). This clearly shows researchers' awareness of the importance of studying subskills or component processes underlying proficiency (especially reading comprehension) for a deeper understanding about linguistic interdependence, CUP and cross-linguistic transfer in the education of d/Deaf children. Importantly, the significant mean correlations (mostly medium and large effects), as shown in Table 1, suggest that transfer does not have to happen just for 'literate proficiency'; and there is much of sign language that can contribute to spoken/written language development.

The number of effect sizes, nonetheless, showed notable variations across different types of cross-linguistic relationships. On the two ends of the spectrum, whereas two cross-linguistic relationships (i.e., those of fingerspelling and sign language comprehension with reading comprehension) were high-evidence (Jeon & Yamashita, 2022; $k\geq 15$), language production received very limited attention in either sign language or spoken/written language. The latter might be related to the paucity of readily available sign language assessments and the length of time for scoring production data. It suggests a clear gap to be filled in future research. Among spoken/written language competences, reading comprehension received the greatest attention, which was perhaps no surprise, given its importance both in its own right and for disciplinary learning in schools.

RQ2 magnitude of cross-linguistic correlations

Significant and medium to large correlations were found for all the cross-linguistic relationships meta-analysed. Not only was construct-level transfer observed between corresponding competences in sign language and spoken/written language, but there was a crossover effect of lower-level sign language skills on higher-level spoken/written language skills (Hipfner-Boucher & Chen, 2016).

Construct-level transfer

PA. PA in sign language and spoken language showed a significant and medium correlation ($r=0.462$). This correlation seems similar in magnitude to those meta-analysed between L1 and L2 PA in spoken bilingual learners, such as $r=0.44$ in Ke et al. (2023) across all languages and $r=0.46$ in Yang et al. (2017) focused specifically on L1 Chinese and L2 English (two linguistically distant languages). This finding lends support to linguistic interdependence at the phonological level; or that signing bilinguals' sign language PA could be transferred to support their PA development in the spoken language. A question to ask is perhaps how this facilitative effect is achieved across modalities. In fact, the modality aspect is often where debates exist on linguistic interdependence on the one hand (Mayer & Wells, 1996) and phonology in learning to read on the other for d/Deaf children (Miller & Clark, 2011; Petitto et al., 2016). In discussing visual sign phonology, Petitto et al. (2016) argued that successful learning to read is 'not between print and *sound*, but between print and the abstract level of language organization that we call phonology—signed or spoken' (p. 367; emphasis original). Likewise, Koda (2005) argued, toward proposing the TFM, that the sensitivity to regularities in language, while evolving through learning and using a given language, is 'distinct from linguistic knowledge in that it denotes a basic understanding of the language's general structural properties, independent of specific linguistic instantiations' (p. 311). Following this distinction between (phonological) knowledge and awareness, what links up phonological aspects of sign language and spoken language developmentally in d/Deaf children is perhaps not the knowledge of phonological units represented in a different modality but the abstract understandings of fundamental principles underlying phonology. In other words, although 'parameters' such as handshape, location, movement, palm orientation and non-manual markers are sign language specific, the insights pertaining to phonemes/parameters combining in principled ways could be highly metalinguistic in nature and language/modality-neutral and transferable.

This metalinguistic account perhaps should not be interpreted that PA in sign language and spoken language are identical. In fact, in cross-linguistic studies of reading processes and acquisition, PA is noted to be multifaceted. Variations in PA also exist across spoken languages reflecting their respective psycholinguistic grain size or 'granularity of spelling-to-sound mappings' (Ziegler & Goswami, 2005, p. 3); and the relative importance of different PA aspects for reading acquisition may also vary across languages (Verhoeven & Perfetti, 2017). These variations across languages (and writing systems) could also be manifested in unimodal bilingual readers (Branum-Martin et al., 2012). Future research is needed on how different types/aspects of sign language PA might show differential levels of associations with spoken language PA and reading (or in other words, how different aspects may be more or less transfer-ready across modalities and languages) toward generating more nuanced understanding about linguistic interdependence at the phonological level.

Lexico-semantic knowledge

Another notable construct-level cross-linguistic correlation pertained to lexico-semantic knowledge, for which a mean correlation of 0.407 was found ($p<0.001$). Although compared to other cross-linguistic relationships (see Table 1), this correlation showed a medium rather than a large effect, it appeared much higher than what was found of hearing bilingual children. Yang et al.'s (2017) meta-analysis, for example, showed a mean correlation of 0.10 ($p < 0.01$; a small effect) among school-aged Chinese-English bilingual children. The current finding lends clear support to Cummins' (2007, 2021) emphasis on conceptual knowledge as an area where linguistic interdependence exists. The knowledge of words (and the world) established in sign language can provide the semantic/meaning basis for spoken/written vocabulary learning. Experiments on signing bilinguals, in the absence of their phonological representations in the same modality between the two languages, showed activation of sign language translations in the processing of written words semantics (e.g., Morford et al., 2011; Villwock et al., 2021). Villwock et al.'s (2021) findings on the cross-modal facilitation effect in middle schoolers suggested that deaf children could benefit from sign language from a relatively early stage of reading acquisition.

A further question is then: what aspects of lexico-semantic knowledge may be interdependent over and beyond a shared meaning basis that characterises bimodal, bilingual learning and use? Ordóñez et al. (2002) reported significant and medium cross-linguistic correlations for paradigmatic relations or superordination ($r = 0.34$–0.46) between L1 Spanish and L2 English in Spanish-speaking children in the United States; yet the correlations for communicative adequacy ($r = 0.16$) and syntagmatic relations ($r = 0.18$) showed a small effect and did not reach significance. In explaining the stronger correlation for superordination, the authors proposed two mechanisms: a direct lexical effect (which is related to the semantic basis shared across languages which we noted above) and a metalinguistic route. The latter is particularly interesting. As argued by the authors, 'children who have mastered the skill of fitting superordinate into the structure of a formal definition in Spanish may find it easier to deploy the same skill in English' (p. 726). Such a metalinguistic route may apply to bimodal bilingualism as well. In fact, the lexico-semantic knowledge broadly coded in the present review concerned knowledge of meanings stored in the lexical memory as well as skills related to lexical use and semantic processing (see Appendix S1). While a picture-based, definition task was commonly used (which focused on the form-meaning connection aspects of vocabulary knowledge), several studies (e.g., Hoffmeister, 2000; Novogrodsky et al., 2014) focused on vocabulary depth knowledge with tasks that seemed to touch on the metalinguistic route proposed by Ordóñez et al. (2002).

Morpho-syntactic/grammatical knowledge

The medium correlation found for morpho-syntactic/grammatical knowledge ($r = 0.471$, $p < 0.001$) may be a surprise, considering that sign language and spoken language are known to show many notable differences in grammar (Valli et al., 2011). One explanation may be related to the distinction between knowledge and awareness in measuring morpho-syntactic/grammatical competence. While syntactic knowledge pertains to 'an understanding of the canonical word order (subject-verb-object) in English sentences', syntactic awareness 'reflects the realisation that the order in which words are presented determines sentence meaning' (Koda, 2005, p. 311). Accordingly, whereas syntactic knowledge can be very language-specific reflecting the typological distance between two languages, metalinguistic understandings about (all) languages operating in rule-bound ways may provide positive transfer facilitation support. This metalinguistic account also seems to be supported by a few studies on transfer of syntactic awareness in linguistically distant languages such as Chinese and English (e.g., Siu & Ho, 2015; Tong et al., 2021). It should perhaps be distinguished from traditional views on transfer which tend to highlight grammatical differences as resulting in 'negative transfer' of *knowledge* of L1 rules (Wolbers et al., 2014).

This metalinguistic account, nonetheless, should be applied with a caveat, because one should not ignore how morpho-syntactic/grammatical knowledge was measured in the included studies. To illustrate, Crume et al. (2021) and Lederberg et al. (2019) reported a correlation larger than 0.60. In both studies, 'English receptive syntax' was measured using English-like signing such as 'The little bird is eating (LITTLE BIRD EATING)' (Crume et al., 2021, p. 162), where there seemed to be ASL-based semantic involvement in addition to the target focus on English word order. In other words, the large correlation between receptive syntax in ASL and English may partially reflect both measures' involvement of ASL vocabulary. In Hermans et al. (2010), where 'morphological and syntactic aspects of spoken Dutch' were tested by children's speech therapists and did not seem to involve signing, the correlation was 0.346 (medium) for the older group and −0.179 for the younger group. Caution should thus be taken for interpreting the linguistic interdependence at the morphosyntactic/grammatical level in signing d/Deaf children.

Crossover effects

Table 1 also shows some crossover effects defined as the correlations of sign language competences with reading outcomes. There has been a strong interest in this type of effects in L2/bilingual reading research framed to test cross-linguistic transfer. Hipfner-Boucher and Chen (2016) noted this as the 'third perspective' on transfer research where 'correlation-based statistical procedures' are used to 'quantify the amount of variance accounted for by specific skills in predicting word-level or text-level reading comprehension across languages' (p. 104).

Word reading

Among the five sign language correlates meta-analysed for word reading, fingerspelling received the greatest attention (see Table 1). Padden and Hanson (2000) contended that fingerspelling represents a 'missing link' between sign language and written language and highlighted the importance of fingerspelling for reading acquisition. The high correlation between fingerspelling and word reading ($r=0.645$) could partly be explained by the fact that fingerspelling encodes orthographic information, which is fundamental to word reading (e.g., Deacon et al., 2019). Lexicalised fingerspelling may also contribute to the recognition of corresponding written words, albeit less directly, as in the case of more direct mapping of fingerspelled 'letters' on those in written words. While this higher correlation suggests that cross-linguistic transfer facilitation effect of fingerspelling on learning to read, a caveat is also in order. Padden (2005) discussed d/Deaf children's learning of fingerspelling twice, importantly the second time when fingerspelling (especially metalinguistics) undergoes further development and becomes refined, after children are exposed to written language and develop sub-lexical awareness of written words. In other words, the correlation between fingerspelling and word reading may conversely suggest the influence of the latter on the former as well.

Compared to fingerspelling, the crossover effect of other sign language correlates on word reading were perhaps less straightforward. Melby-Lervåg and Lervåg (2011) and Ke et al. (2023) reported, in their meta-analyses on L1 PA and L2 decoding, a correlation of 0.44 and 0.39, respectively. In the present study, a significant correlation of a similar magnitude ($r=0.40$) was found between sign language PA and word reading. While this effect could mean transfer facilitation from sign language PA, it begs the question of how the facilitation was achieved in a 'crossover' manner. There are still debates on the mechanisms of crossover effects like this in bilingual reading research. For example, developmentally, does L1 PA contribute to L2 word reading directly, or rather indirectly via its effect on L2 PA (i.e., via construct-level transfer)? Such an issue could not be directly tested as a result of the present meta-analytic focus on bivariate correlations only. Considering the construct-level transfer discussed earlier for PA (see also Petitto et al., 2016) and intra-lingual correlations of spoken language PA with word reading (Mayberry et al., 2011), it seems reasonable that some transfer facilitation may at least be indirect. The issue of phonology and reading in d/Deaf children is so complex that there are still debates (e.g., McQuarrie & Abbott, 2013; Miller & Clark, 2011; Petitto et al., 2016). Questions still seem to remain as to how sign language PA may be directly serviceable in reading acquisition and how transferred sign language PA may need to be accommodated into written language input to eventually support reading development (Koda et al., 2014).

Reading comprehension

Cross-over effects were also found for reading comprehension (see Table 1). Compared to word reading, the mechanisms for reading comprehension effects may be even more complex. Melby-Lervåg and Lervåg (2011) reported that L1 decoding had a significant but small correlation with L2 reading comprehension ($r=0.24$). Ke et al. (2023) reported a very small and non-significant correlation between L1 orthographic awareness (OA) and L2 reading comprehension ($r=0.05$). These correlations, however, did not directly shed light on the present review, because the literate skills (i.e., OA and decoding) did not pertain to sign language. What seems noteworthy is perhaps the crossover correlation, or the lack thereof, reported on L1 oral proficiency and L2 reading comprehension in Melby-Lervåg and Lervåg (2011). Melby-Lervåg and Lervåg (2011) coded oral proficiency (both L1 and L2) based on vocabulary knowledge and listening comprehension. While a significant intra-lingual correlation was found between L2 oral language and L2 reading comprehension ($r=0.46$), the inter-lingual correlation between L1 oral language and L2 reading comprehension was minimal and did not achieve significance ($r=0.04$).

Our meta-analytic results, however, were very different. For example, sign language lexico-semantic and grammatical knowledge (which underpinned sign language comprehension) both showed a significant and large correlation with reading comprehension, rs$=0.517$ and 0.521, respectively. These may suggest that the conceptual/meaning basis and grammatical understandings may be more serviceable cross-linguistically in reading and text comprehension among signing bilingual readers than in their hearing counterparts. In addition, the large correlation sign language comprehension (perhaps akin to listening comprehension measured of spoken language in hearing readers) had with reading comprehension ($r=0.517$) suggests that higher-level comprehension abilities where pragmatic skills are involved could also transfer to facilitate reading comprehension development. Accordingly, the possibility discussed earlier of an indirect mechanism via construct-level transfer for word reading may also apply to reading comprehension in bilingual d/Deaf readers. Rosenberg (2020) reported high correlations of ASL vocabulary and syntax with English reading comprehension (rs ranging from 0.65 to 0.77). ASL comprehension and reading comprehension also showed a high correlation ($r=0.66$). Controlling for ASL vocabulary and syntax, however, the correlation between ASL comprehension and reading comprehension was reduced substantially ($r=0.12$). Taken together, these findings might suggest that the crossover effects of sign language vocabulary and grammatical knowledge on English reading comprehension might be achieved indirectly via ASL comprehension.

Fingerspelling showed a high correlation with reading comprehension ($r=0.622$). This crossover effect may reflect the importance of fingerspelling for word reading as discussed earlier as well as that of word reading for reading comprehension (see Jeon & Yamashita, 2022, which reported $r=0.586$ between L2 word decoding and L2 reading comprehension). Other possible (indirect) routes may also apply considering that fingerspelling showed a correlation of 0.467 with spoken/written language lexico-semantic knowledge (see Table 1); and that vocabulary knowledge is fundamental for text reading and comprehension (meta-analytic $r=0.724$ in Jeon & Yamashita, 2022). The mechanisms underlying the transfer facilitation from fingerspelling on reading comprehension remain to be explored in the future with statistical methods that involve mediation analysis.

Another interesting finding for reading comprehension was its high correlation with Manually Coded English (MCE) ($r=0.566$). Five studies (e.g., Chamberlain & Mayberry, 2008) compared how d/Deaf students fared on comprehension in MCE versus written English and explored how MCE comprehension correlated with English reading comprehension. The high correlation was perhaps no surprise because texts were signed following English word order and intra-lingually syntactic knowledge is fundamental to reading comprehension (meta-analytic $r=0.697$ in Jeon & Yamashita, 2022). In addition, lexical representation using sign language words perhaps also provides the semantic basis for text comprehension across languages. Inferencing skills may also help connect MCE comprehension and English reading comprehension. If these conjectures on different routes of connections all hold, the high correlation should perhaps not be interpreted as simply justifying the use of MCE per se in reading instruction for d/Deaf children. Rather, it may suggest that the subskills underpinning MCE comprehension, such as English grammar, sign language vocabulary, and inferencing skills, could be 'decomposed' for separate instructional attention.

RQ3 moderator effects

A very important issue for understanding linguistic interdependence or cross-linguistic transfer facilitation is how that may be conditioned on varied factors (Chung et al., 2019; Ke et al., 2023). Moderator analysis, in this respect, can make a notable contribution to knowledge because those factors may not have been directly tested or may not be testable in any individual primary study. Our moderator analysis results have shed much light on understanding study heterogeneities and filled some important gaps in current debates on bilingual deaf education in light of the LIH, CUP and transfer.

Age/grade

Age/grade showed a significant moderator effect for the relationship between fingerspelling and reading comprehension. While for both elementary school and adult/university students, the correlation showed a large effect, it was significantly higher ($r=0.698$) in the former group. This result suggests a stronger association between fingerspelling and reading development among young children and highlights instructional attention to fingerspelling (including metalinguistics of fingerspelling) in early reading instruction.

For lexico-semantic knowledge, the large effect among secondary school students ($r=0.580$), in comparison to a medium effect among elementary school students ($r=0.418$), may suggest a greater capacity in older students to utilise semantic information and lexico-semantic awareness in bilingual learning and use. The medium effect in adult/university students ($r=0.394$) may, in this respect, stand as a surprise. We conjecture that this may be because, at their distinct stage of education, university students' lexico-semantic development may be much more reliant on and distinguished by the quantity and quality of written language exposure and lexical use (e.g., reading books and academic writing) than by their sign language knowledge base.

The pattern, interestingly, seemed to be the opposite for morpho-syntactic/grammatical knowledge at the construct level. Elementary school students demonstrated a medium effect ($r=0.468$) and this effect was also significantly stronger than the small effect ($r=0.271$) among secondary school students. While this finding may suggest stronger interdependence at the grammatical level in younger learners, caution must be taken. This is because three of the five effect sizes on elementary school children, that is, Crume et al. (2021) and Lederberg et al. (2019; including a bimodal and a unimodal group), happened to employ English-like signing (where semantic access was via ASL) to measure English receptive syntax. For those three effect sizes, *r* ranged from 0.619 to 0.660 (see Table S1). In other words, the involvement of sign language in assessing English grammatical knowledge might have inflated the correlations in the subgroup of elementary school students.

The large effect in elementary school children ($r=0.586$) and the medium effects in secondary school ($r=0.483$) and university students ($r=0.462$) perhaps suggest long-term implications of sign language comprehension (e.g., inferencing skills and comprehension strategies) on reading and text comprehension. It also seems to underscore the importance of promoting comprehension skills and strategies in sign language early on in elementary school to facilitate d/Deaf children's written language comprehension.

Signer status

Many studies aimed to compare outcomes in native and non-native signers, often defined as DCDP and DCHP, respectively; and DCDP's stronger performance on some spoken/written language skills is often interpreted to support linguistic interdependence because of this group's presumably stronger sign language proficiency. Nevertheless, studies were rare that directly measured sign language competences, correlated them with spoken/written language competences, and compared the strength of cross-linguistic correlations between DCDP and DCHP to shed light on the interdependence. In this respect, the present meta-analytic findings based on signer status as a moderator have filled a notable research gap.

Although signer status did not show a significant moderator effect for any cross-linguistic relationship, the differing size of the effects among subsamples still provides some important information. The different pattern for lexico-semantic versus morpho-syntactic/grammatical knowledge seems particularly interesting. Table 4 shows that, for lexico-semantic knowledge, the balanced group showed a large effect ($r=0.600$) whereas the effect was medium ($r=0.381$) for the non-native signers group. This appears to suggest that non-native signers, compared to native signers, might be less active in utilising sign language lexico-semantic resources in spoken language learning and use. Table 5, on the other hand, shows an opposite pattern for morpho-syntactic/grammatical knowledge: whereas the effect was large for the non-native signers group ($r=0.699$), it was medium for the balanced group ($r=0.436$). We speculate that this discrepancy might be related to the distinctive nature of the two types of linguistic knowledge. While for native signers, semantic resources (e.g., a shared meaning base) could be highly shareable across languages, their sensitivity to grammatical differences between sign language and spoken/written language might make them less inclined, in comparison to non-native signers, to utilising morpho-syntactic/grammatical skills in the former as a resource for their learning of the latter.

Table 9 showed that native signers ($r=0.385$) demonstrated a medium effect whereas non-native signers ($r=0.540$) and the balanced group ($r=0.568$) both showed a large effect. The reduced 'interdependence' for comprehension among native signers seems surprising, because presumably they would be more active and adept with using their L1/sign language comprehension skills and strategies in reading comprehension. Because the result for native signers was based on only two effect sizes (as opposed to 14 for non-native signers) in this review, we hesitated to make any strong conjecture on this finding. One speculation might be that native signers in those two studies were coincidently very proficient in their L1, which means statistically there might be less variance in sign language comprehension for a strong correlation to emerge with their reading comprehension.

School/programme type

There have been active debates on whether bilingual schools/programmes have achieved the intended goals to raise d/Deaf students' academic outcomes (Mayer & Trezek, 2020, 2023; Paul & Yan, 2023; Scott et al., 2021). Among these debates, there has been little attention to how children educated in different types of schools or programmes may demonstrate differential levels of linguistic interdependence between sign language and spoken/written language. Presumably, children educated in bilingual programmes that underscore the use of sign language for instructional and communication purposes would demonstrate more active engagement with sign language skills and strategies in learning and using spoken/written language, including reading comprehension. As a result, more salient correlations of sign language competences with spoken/written language competences might emerge in them in comparison to their peers educated in programmes characterised by TC/SimCom and oral approaches.

This was exactly the case based on the analyses with school/programme type as a moderator. In fact, for all four cross-linguistic relationships where such moderator analysis was conducted, the bilingual group consistently demonstrated a higher correlation than the TC/SimCom group. For example, for the cross-linguistic correlations of both lexico-semantic knowledge and morpho-syntactic/grammatical knowledge with reading comprehension, the bilingual group showed a large effect ($r=0.505$ and 0.531, respectively) whereas the TC/SimCom group showed a small effect ($r=0.175$ and 0.113, respectively); and the correlations also significantly differed between the two groups. These meta-analytic findings have filled a notable niche in the primary literature because no studies aimed to directly compare cross-linguistic correlations in d/Deaf children educated in different types of schools/programmes, which might be related to the decreasing popularity of TC/SimCom, as opposed to sign language, as a result of shifting language and deaf education policies. These findings also corroborate previous review results on hearing L2/bilingual readers that instructional context could have a notable impact on linguistic interdependence and cross-linguistic transfer (Chung et al., 2019; Yang et al., 2017).

Sign language comprehension task

Because of the relatively small number of effect sizes for cross-linguistic relationships for the present review, our coding for task type only focused on reading comprehension where the largest number of effect sizes ($k=75$) were extracted. And among the correlates of reading comprehension, we also coded task type for sign language comprehension, which was the sign language correlate that produced the largest number of effect sizes ($k=22$) with reading comprehension. As shown in Table 9, while task type did not demonstrate a significant moderator effect for either sign language comprehension or reading comprehension, the size of the effect showed some interesting findings. For example, when sign language comprehension tasks focused on passage comprehension, the correlation with reading comprehension demonstrated a large effect ($r=0.585$); whereas for the task focused on sentence comprehension, the effect was medium ($r=0.449$). The pattern for reading comprehension tasks appeared similar albeit less salient ($r=0.527$ vs. $r=0.495$). Taken together, these findings seem to suggest a more salient transfer facilitation effect at the passage level. This does not seem surprising, considering that passage-level comprehension, compared to sentence comprehension, involves the orchestration of a greater number of potentially transferable skills and strategies, notably the inferencing skills and comprehension strategies.

Limitations and future directions

A few limitations are noted of this review and the primary literature. First, this review only focused on cross-linguistic correlations; intra-lingual correlations within sign language and spoken/written language were not coded and meta-analysed (Mayberry et al., 2011; Zhang et al., 2023). This has limited our interpretation, to some extent, for the crossover effects on word reading and reading comprehension. Second, the effect sizes coded for this review were largely zero-order correlations. Without controlling for cognitive and socio-demographic factors, the correlations between sign language and spoken/written language competences might be overestimated. Third, existing evidence on linguistic interdependence and cross-linguistic transfer facilitation in L2/bilingual reading has been largely based on concurrent correlations. Signing d/Deaf children were found to be no exception. More robust evidence should perhaps be longitudinal in nature, showing, for example, how developmentally spoken/written language skills at a later time depend on sign language skills at an earlier time (Chung et al., 2019; Hipfner-Boucher & Chen, 2016; Koda, 2008).

Finally, it is clear from this review that not all sign language competences potentially transferable received (equal) attention in the literature. A notable skill that received substantial attention in the literature on cross-linguistic transfer and L2/bilingual reading but was barely the case for d/Deaf readers is MA, the ability to reflect on and manipulate morphemes and morphological structure of words (Ke et al., 2021; Kuo & Anderson, 2006). Sign language morphology, in terms of its visual–spatial representation of morphemes and its simultaneity, differs significantly from spoken language morphology (Aronoff et al., 2005; Valli et al., 2011). Nevertheless, metalinguistic insights at the morphological level, such as awareness of lexical compounding, might be transferable between sign language and spoken language as in the case of some typologically distant spoken language (Pasquarella et al., 2011; Zhang, 2013). Potential transfer of MA warrants to be tested on signing d/Deaf readers in the future.

CONCLUSIONS

This paper has synthesised the literature that explored linguistic interdependence and cross-linguistic transfer between sign language and spoken/written language in signing d/Deaf learners. In particular, we meta-analysed the correlation coefficients for a range of cross-linguistic relationships and conducted moderator analyses that shed light on the complexity and conditioning of interdependence and transfer. Among many important findings, there was notably substantial attention to correlating lower-level as well as higher-level competences in sign language with reading comprehension. Moving beyond cross-linguistic correlations for general proficiency or global competence measures to sub-skills underlying proficiency has contributed significantly to the understanding about the LIH, CUP, transfer facilitation and associated constructs in the context of educational development in d/Deaf children. The meta-analytic findings lend further support to the legitimate application of theorisations on L2/bilingual reading to signing or bimodal bilinguals and demonstrate that transferable competences do not have to be written language skills. More important, our findings have significantly expanded current understandings about the mechanisms of cross-linguistic transfer facilitation in d/Deaf students' reading development, although the crossover effects remain to be further tested through primary and meta-analytic studies in the future. Some moderator effects have filled notable gaps in the literature where, for various reasons, the conditioning of linguistic interdependence and transfer was minimally tested in individual primary studies.

The meta-analytic findings have also shed light on policy and practice related to the education of d/Deaf children. An overall recommendation based on the findings is that some sign language skills deserve special attention and could and should perhaps be capitalised on instructionally through such approaches and strategies as 'teaching for transfer'; and instructional goals may also need to be differentiated and developmentally responsive (Ballinger et al., 2020; Cummins, 2007, 2021). To illustrate, fingerspelling and its metalinguistics may deserve special attention in the early stage of reading acquisition; developing comprehension skills and strategies for extended discourse in sign language, such as inferencing, may particularly benefit reading comprehension; likewise, explicit instruction to develop metalinguistic insights into sign language will benefit signing bilingual children, especially non-native signers or DCHP children. Programme and instructional goals of course should entail opportunities for children to actively use sign language. In a nutshell, instructional planning based on linguistic interdependence and transfer need to be more nuanced and would thus seem far more fruitful in line with the cross-linguistic relationships reviewed in this paper than under a general guide that d/Deaf children's sign language proficiency should be cultivated.

An extension of the practical implications of the LIH and transfer facilitation is perhaps how spoken/written language skills may need to be cultivated. This is an area where big debates exist. It is our view that transfer-induced benefits could not and should not replace high-quality instruction that cultivate intra-lingual skills such as lexico-semantic knowledge, grammatical understandings, comprehension skills and strategies in the spoken/written language itself. In fact, none of the theorisations on L2/bilingual reading development denies the critical importance of developing the fundamental skills intra-lingually in the L2 (Cummins, 2021; Koda, 2008). The TFM (Koda, 2008) in particular underscores that transferred L1 skills need to be accommodated into the L2 system through high-quality exposure to L2 input. In this respect, the lasting debates on whether phonology plays an essential role in learning to read among d/Deaf children should perhaps not be interpreted toward an omnibus rejection of needs for explicit instruction on component skills underlying reading and literacy development. Hermans et al. (2008) showed how transferred competence from sign language was not sufficient for the development of lexical quality in the spoken/written language (e.g., high-quality lexical and sublexical representations that enable efficient word recognition); and underscored how focused instruction in the spoken/written language is fundamental. While balanced views have now guided many discussions on bilingual deaf education, there are still active debates around how signing systems may or may not have a legitimate 'modality-bridging' role (see Knoors & Marschark, 2012; Mayer & Trezek, 2020; Paul & Yan, 2023; Scott & Henner, 2021). Future research, especially longitudinal and experimental research, is much needed to further understand how sign language and signing systems may work in tandem in supporting d/Deaf children's literacy development.

AUTHOR CONTRIBUTIONS

Dongbo Zhang: Conceptualization; methodology; data curation; investigation; formal analysis; writing – original draft; writing – review and editing; visualization; project administration. **Sihui Ke:** Methodology; data curation; conceptualization; writing – review and editing; investigation. **Junhui Yang:** Conceptualization; investigation; data curation; writing – review and editing. **Hannah Anglin-Jaffe:** Conceptualization; writing – review and editing; investigation.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ETHICS STATEMENT

This article does not contain any studies involving human participants performed by any of the authors.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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