Educational Research Review 46 (2025) 100659

Contents lists available a ScienceDirect

Educational Research Review

journal homepage: www.elsevier.com/locate/edurev

Review

The c itive rofile of adults with low literacy skills in alphabetic orthographies: A systematic review and c mparison with developmental dyslexia

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A R T I C L E I N F O

Keywords:
Functional illiteracy
Low literate
Adult basic education
Dyslexia
Reading

A B S T R A C T

Dealing with ext is crucial in modern societies. H wever, everyone acquires sufficient literacy skills during school education. This systematic review summarizes and synthesizes research *adults with low literacy skills* (ALLS) i alphabetic writing systems, i cludes results from behavioral and eurobiological studies, and compares hese findings with hose developmental dyslexia iven hat his developmental disorder is e possible explanation for low literacy skills in adulthood. Twenty-seven studies focusing he cognitive rofile f ALLS met he hree redefined criteria f reading level, age, and education. Results showed hat ALLS erformed worse han literate adults i various tasks at skill and information processing level, and exhibited structural and functional differences a he neurobiological level. The cognitive rofile of ALLS was closer hat f primary school children han of literate adults. However, relative children, ALLS' literacy skills relied less phonological and m re rthographic strategies. A arrative comparison f results with meta-analyses developmental dyslexia showed large, hough complete, verlap i he cognitive rofiles. The resent results helps better understand he literacy skills and reading-related cognitive functions of ALLS and may support the development f tailored interventions directed he specific cognitive difficulties ALLS have.

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[1] Equal distribution.

https://doi.org/10.1016/j.edurev.2024.100659
Received 17 January 2024; Received in revised form 7 October 2024; Accepted 8 December 2024
Available online 16 December 2024

1. Introduction

Active articipation in modern societies requires dealing with ext, for which a least reading and writing skills, i.e., *literacy,* are needed. Unlike oral language acquisition, literacy acquisition requires explicit i struction (Lachmann & Bergström, 2023), which riggers the c rdination and fine-tuning f re-existing cognitive functions (Huettig, olinsky & Lachmann, 2018; Lachmann, 2002) create literacy-specific cognitive rocedures. After years f intensive raining (Froyen et al., 2009) hese become automatized (Nicolson & Fawcett, 2007, 2018), which is associated with literacy-specific structural and functional changes i he brain (Carreiras et al., 2009; Dehaene e al., 2010; Hervais-Adelman e al., 2019; Skeide e al., 2017). Large-scale international a d national s udies have shown, however, hat even i *Western Educated Industrialized Rich Democratic* ("WEIRD") societies, a considerable art f the adult ulation does possess such basic literacy skills (OECD, 2013). For instance, according he PIAAC Survey of Adult Skills (OECD, 2019), every sixth adult i he European Union can complete only simple d cumen ts and is able locate only single ieces of information from short exts with little c mpeting information. According he German ational Level One Study (Grotlüschen et al., 2020), 12.1% f he German-speaking ulation (18–64 years) can read and write letters, words, and sentences but exts, t eve short es.

The resent literature review examines the c itive rofile of a s ecific roup of individuals with low literacy skills, i.e., those who have received (at least some) formal education in written language but still resent low reading and writing skills hat revent hem from effective articipation in society. This roup was first described by UNESCO (1979) as *Functional Illiterates*. As his term is w considered stigmatizing, it is longer used. In his paper, we use he term Adults with Low Literacy Skills (ALLS), although various terms have been adopted i research a d ractice refer this specific ulation (e.g., struggling adult readers, oor reading adults, or adults in foundational education), which may or may exactly reflect ur arget roup (see erminology discussion in Perry et al., 2017; Rosen, 2022).

In WEIRD societies, relative *literate adults (LA,* i.e., individuals with adequate reading and writing skills; see UNESCO, 1979), ALLS ften show a lack f positive school and learning experiences, lower emotional stability and lower socioeconomic security i heir families during childhood (D bert & Hubertus, 2000; Egloff e al., 2011, pp. 11–31; Nickel, 2007). In adulthood, hey are more likely be among he older, male, and less educated art f he population, and more likely have an immigration background (Grotlüschen et al., 2019). Therefore, besides education, socioeconomic, sociodemographic, and individual factors (e.g., cognitive, emotional, and motivational raits) might also contribute, either individually or in combination, low literacy skills.

Two main approaches have been adopted f r the identification of ALLS. O he one hand, some studies have adopted a wide a d inclusive selection approach, by which ALLS express difficulties in deali with written materials and are enrolled i adult learning and education programs (e.g., adult basic education, "second chance" programs, adult literacy or secondary education classes). The articipants f such rograms ften exhibit lower scores e r more reading components han he average f he reference ulation (e.g., pseudoword decoding, word reading, reading c mprehen sion). Note, however, i hese s udies there is usually predefined criterion for a low reading level (e.g., expressed as maximum f he rade equivalency score, GE score). Thus, ALLS e rolled in these education programs usually have heterogeneous reading skill levels, ranging from 2nd 12th GE score (e.g., McKoon & Ratcliff, 2017; Mellard et al., 2013). On he ther hand, some studies have adopted a stricter selection approach by which he definition of ALLS is based u a explicit reading level criterion (e.g., 4th GE score, Boltzmann & Rüsseler, 2013; Grosche, 2012).

In WEIRD s cieties, only a small roportion f children show ersistent and serious difficulties in literacy acquisition and development despite adequate schooling and i he absence f eneral learning roblems. The latter ulation qualifies for a diagnosis f *developmental dyslexia* (DD), a neurodevelopmental disorder caused by a circumscribed deficit in brain development during early childhood (World Health Organization, 2022). The *Multi-level framework of Developmental Dyslexia* (Lachmann & Bergström, 2023; see also Lachmann et al., 2022) describes he ransition from hat causal deficit at he *neurobiological level* possible deficits at he *n-formation processing level* hat may impair the reading-related cognitive functions (e.g., honolog ical processing, auditory and visual processing; e.g., Becker et al., 2001; Farmer & Klein, 1995; Stein, 2018a; Stein, 2018b; Steinbrink e al., 2014) required build a literacy-specific rocedure. Impairments a he *nformation processing level* would lead s ecific learning deficits i reading and writing (*skill level*), which, in turn, would lead rer han expected school performance (*academic achievement level*) a d a br ad variety f ossible secondary symptoms (*secondary level*). This ransition from one level he ext is neither a e-way rack r unavoidable. I deed, individual (e.g., motivation, cognitive ability) and e vironmental (e.g., culture, deprivation, socioeconomic status; Frith, 1985, 1999; Steinbrink & Lachmann, 2014) factors may i fluence his between-level ransition and he impact may be reciprocal (Lachmann & Bergström, 2023). Moreover, he ransition of deficits he skill level can be minimized hrough rofessional and argeted revention a d intervention (Klatte et al., 2018; Tallal & Jenkins, 2018), which i urn w uld also influence he achievement level (e.g., compensation for disadvantages).

Similar individuals with DD, ALLS might have failed in literacy-specific procedural learning due deficits a he information rocessing level (e.g., honological processing) in interaction with s cioeducational factors. This potential shared cause could explain ALLS' poor reading skills, i cluding difficulties with ext c mprehension as their cognitive resources would be first and f remost invested in basic i formation rocessing and decoding, leaving room for effective high-level processes (Bulajić e al., 2019; see also the Simple View of Reading, Gough & Tunmer, 1986; Joshi, 2018). Indeed, honological rocessing deficits, which are causally related with DD (e.g., Snowling and Melby-Lervåg, 2016), have been found i ALLS, when compared b h LA a d reading-level matched children (Eme, 2006; Greenberg e al., 1997; Grosche, 2012; Mellard et al., 2015; Thompkins & Binder, 2003). In fact, honological deficits explain low literacy skills even better han demographic factors (Landgraf e al., 2012; Vágvölgyi, 2018). Therefore, hono-logical rocessing deficits could be e f he ossible causal factors for low literacy skills in adulthood in WEIRD societies (e.g., Huettig, Lachmann et al., 2018). Additionally, iven the heterogeneity i ALLS, some could have undiagnosed and untreated DD, which due extraneous factors (e.g., low SES, poverty) was left untreated i childhood (Greenberg e al., 1997).

Surprisingly, as shown in a recent systematic review (Vágvölgyi e al., 2021), the research hat addressed his association between low literacy in adulthood and DD is scarce. Although in the review by Vágvölgyi e al. (2021) a broad search strategy was adopted, ly five studies met heir loose i clusion criteria (e.g., low literacy skills were defined as a reading level lower han would be expected from he eneral population). The very limited research c mparing ALLS and DD hat was found was highly heterogeneous in erms f research question and methods, criteria and nomenclature adopted, and inclusion criteria. Hence, i was ssible meaningfully compare and eneralize he findings.

Some narrative reviews have already summarized he current knowledge ALLS and proposed a potential link with DD (e.g., Vágvölgyi e al., 2016). However, hese reviews have usually focused behavioral data and fte failed differentiate between he heterogeneous roups f adults with varying reading levels. Thus, he aim f he resent review was wofold: systematically collect and summarize the available research a specific roup of ALLS, a d narratively c mpare these findings with hose f the available research DD considering: (1) cognitive profiles, (2) potential causes f low literacy skills in adulthood, and (3) intervention rograms for ALLS in alphabetic orthographies. The resent review presents results the c itive rofile.

Novel his review is the i clusion f neurobiological studies in additi those with behavioral results a he skill and information rocessing levels, a d the categorization of all results into a c m rehensive theoretical framework (*Multi-level Framework of Developmental Dyslexia*; Lachmann & Bergstr m, 2023). We also ensured hat ly studies with c mparable ALLS samples were considered via predefined, specific eligibility criteria f reading level, age, and education.

. ethods

The review rotocol was submitted he International Prospective Regis er f Systematic Reviews (PROSPERO: CRD42020179537; Lachmann, et al., 2020). The recommendations f the PRISMA guidelines (Moher et al., 2009) were f llowed.

2.1. Eligibility riteria

Studies published in English or German from 1979 (the year f the first defini ion of functional illiteracy; UNESCO, 1979) a d consisting of quantitative data (quantitative designs) were included. Studies including clinical roups r dealing with -alphabetic orthographies were ut f our scope. As a result of discussions between experts in the field f ALLS and DD and based revious studies in the field f low literacy (functional illiteracy; see Egloff e al., 2011), he arget roup was defined using criteria for (1) *reading level*, (2) *age* and (3) *educational level*.

First, low literacy skills in adults were identified as a *reading level* at or below 5th GE score. By his grade, fluent reading should have been reached in both ransparent (e.g., German) and aque orthographies (e.g., English; Landerl & Wimmer, 2008; Seymour e al., 2003). In determining the reading level, any ype f standardized reading measure was accepted, as long as the reading erformance could be expressed i GE score, r he study included a reference roup consisting f typically developing children at or below Grade 5. A maximum f 2.3% (M+2*SD) f he sample was allowed read better han 5 h GE score.[2]

Second, studies with articipants *aged* from 16 65 years were included. More precisely, a study was accepted only if a maximum of 5% (M-1.645*SD) f he sample was below 16 years ld,[3] and less han 5% (M+1.645*SD) was lder han 65 years[4] if ential clinical cognitive decline had been screened ut f r the latter. The lower inclusion boundary (age ≤16 years) was chosen because in most countries, a least in Europe, his is the minimum age f compulsory education (European Commission/EACEA/Eurydice, 2020). Prominent large-scale studies (e.g., PIAAC; OECD, 2019) also adopt this age criterion.

Third, only studies with individuals who completed at least wo years f f rmal *education* were included. This eriod of direct instruction is considered the minimal eriod eeded acquire the fundamentals f reading and writing skills, i b h ransparent and opaque alphabetic orthographies (Landerl & Wimmer, 2008; Seymour e al., 2003). Only studies involving he maximum f 2.3% (M-2*SD) f individuals with less han wo years f formal education[5] were included. This criterion was important exclude s udies with adults whose low reading skills can be explained by a lack of instructi (e.g., primary illiterates), which did belong he specific arget roup f this review.

2.2. Search strategy

We used a systematic search strategy. The studies were collected from ine bibliographic databases (Dimensions, ERIC, JSTOR, Open Grey, ProQuest, PubMed, PubPsych, Scopus, and Web of Science) i June 2021 (except olinsky & Tossonian, 2023, which was available as manuscript before publication). We used search erms for he identification of studies, which c ain he arget roups a d information relevant with respect the research question (see supplementary materials, Table S1). The search erms were adjusted the requirements and specifications f the databases and were adapted German.

[2] This calculation was a lied only when GE score range was reported or when the limit of 5th GE score was exceeded.
[3] This calculation was only applied when the age range was reported r the minimum limit of 16 years f age was exceeded.
[4] This calculation was only applied when the age range was reported r the limit f 65 years of age was exceeded.
[5] This calculation was only applied when the range of years f education was reported or when wo years were exceeded.

3. Results

3.1. Results of the search

As shown i Fig. 1, he systematic search resulted i 8922 hits. After duplicates were removed, wo independent coders screened each title and abstract. In the case f disagreement, the final decision was made through consensus (agreement between the c ders = 90.1%). The remaining 495 studies were read i full length (full ext screening). A his stage, 460 studies were excluded: 412 did fulfill at least e f the i clusion criteria; 31 did report critical information (e.g., educational background f he articipants)[6]; 18 were inaccessible (e.g., older studies and u available ray literature). Thirty-four studies were identified as eligible f r the systematic review (agreement between the c ders = 92.8%, C hen 's κ = 0.58). Among hose, the 27 studies reporting direct roup comparison(s) between ALLS and a least one reference roup r correlations for ALLS are reported i his manuscript.

3.2. Narrative synthesis of the studies

The 27 eligible studies were ublished between 1988 and 2023; 26 in peer-reviewed journals and one in an edited book. The studies were conducted i he USA ($n = 14$), Germany ($n = 10$), France ($n = 2$), and Belgium ($n = 1$). In most f the s udies participants are labeled as functional illiterates (nine studies), as ersons ssessing poor reading skills (seven s udies), r they were described based upon recruitment i formation (e.g., enrollment i adult education or literacy programs, 11 studies). These different erms reflect he various research fields i vestigating his ic.

3.3. Cognitive profile

Following he Multi-Level Framework (Lachmann & Bergström, 2023), the measures i he studies were assigned hree levels: (1) skill level, i cluding reading and spelling measures (20 studies, see Table S2); (2) information rocessing level, including measures cognitive functions (22 studies; see Table S3); and (3) neurobiological level, including eurobiological outcomes (hree studies). Even when he s udies used he same a d identically defined c struct as a dependent variable (e.g., w rd reading), meaningful meta-analyses of results were feasible due the i clusion of different ypes of reference groups. However, i rder represent he results i a quantified way, effect sizes were calculated. Depending he sample sizes, either Cohen's d (Cohen, 1977) r Hedges' g (Hedges & Olkin, 1985) was calculated for each single comparison and displayed i f rest lots. A value up 0.2 was interpreted as a small, up 0.5 as a medium, and up 0.8 as a large effect size. If a study included several measures, r comparisons and c rrelation

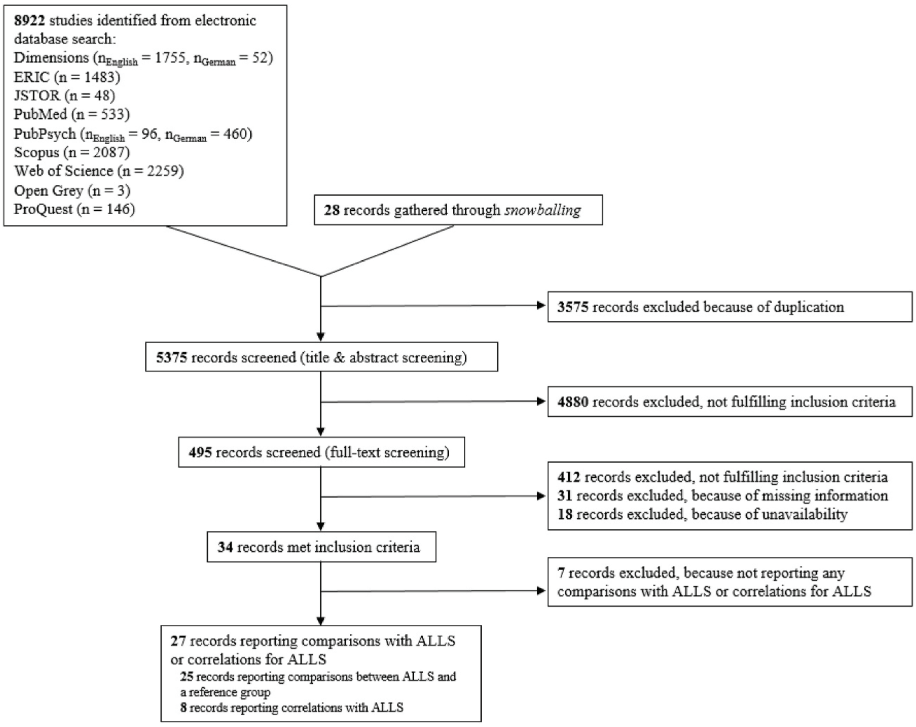

Fig. 1. Flowchart f he systematic literature search and selection rocess.

[6] Authors were contacted without success.

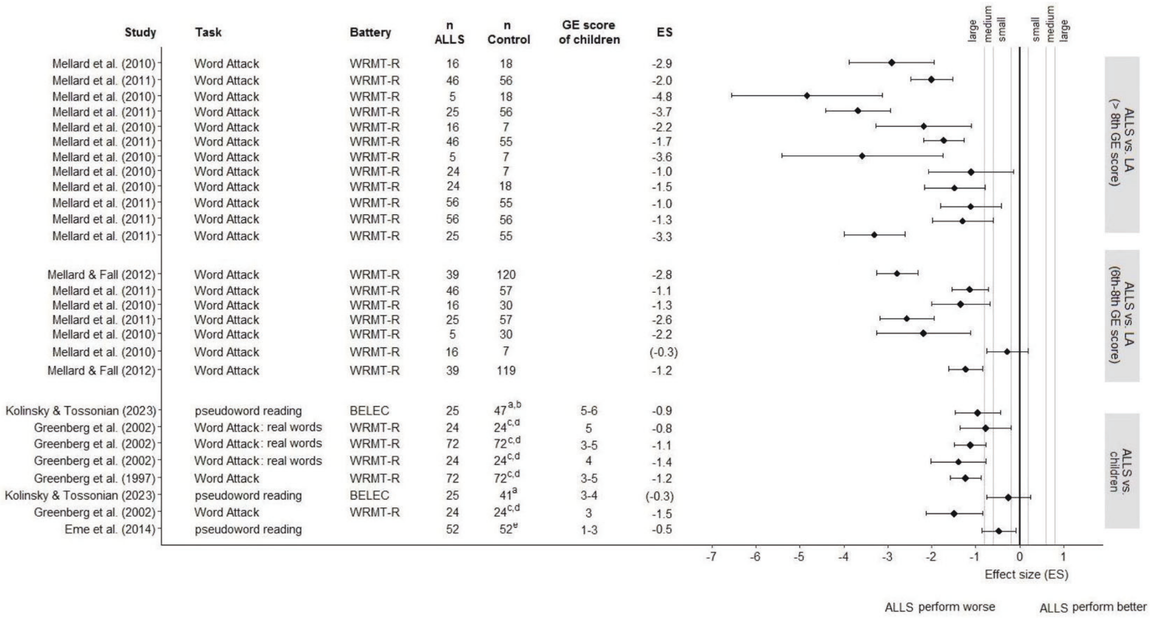

Fig. . Forest lot representing he bservations f pseudoword decoding accuracy
Note. ES = effect size; *ALLS* = adults with low literacy skills; WRMT-R = Woodcock Reading Mastery Test–Revised (Woodcock, 1998); BELEC = Batterie d'évaluation du langage écrit e de ses troubles (Mousty et al., 1994).
Matching variable: [a] Regular word reading accuracy, [b] Regular word reading speed, [c] Word reading accuracy, [d] Decoding accuracy f seudowords, [e] Sentence reading c mprehension.

analyses, he study was included more han once, by each measure (as btain ed measures were rouped separately in accordance their assigned level). In the included studies, ALLS were compared either with children or LA. Although meta-analysis was c - ducted, the results are presented in forest plots (Figs. 2–19) improve clarity. In hese lots, the results are distinguished by he hree comparison roups used i he studies: children, adults with a reading level between 6th and 8th rade equivalency (GE), and adults with a reading level above 8th GE.

3.3.1. Skill level

For assessing the reading-level criterion (i.e., confirmation of low literacy skills), we inspected whether the eligible studies adopted standardized reading skill measures, such as decoding, word reading, reading comprehension, spelling, or composite reading measures. From the 20 studies (see Table S2), 15 compared he erformance f ALLS with hat f ypically-developing children or with LA. Six studies reported correlations between different reading components and s elling skills (i.e., skill level; see Table S4). Two her studies encompassed a comparison between native and non-native speaking ALLS.

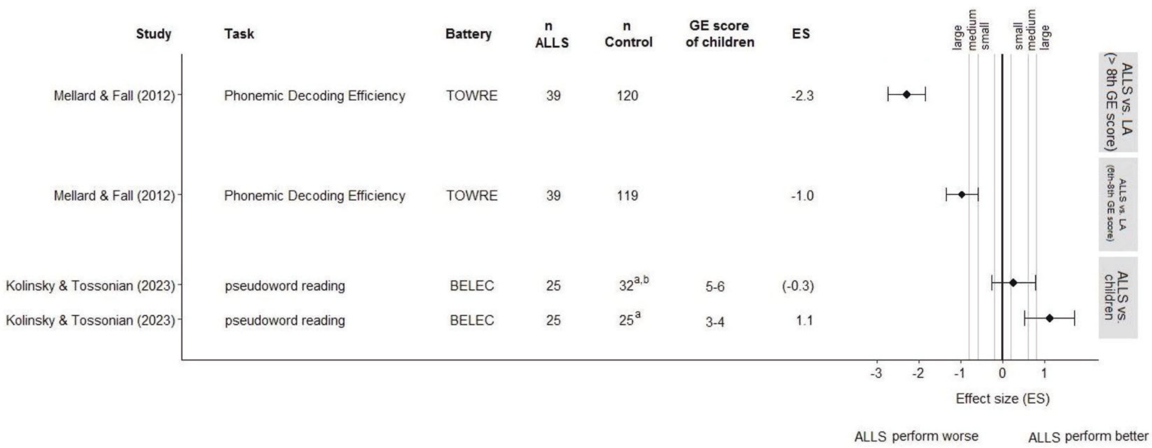

Fig. 3. Forest lot representing he bservations f pseudoword decoding speed
Note. ES = effect size; *ALLS* = adults with low literacy skills; TOWRE = Test of Word Reading Efficiency (Torgesen and Wagner, 1999); BELEC = Batterie d'évaluation du langage écrit e de ses troubles (Mousty et al., 1994).
Matching variable: [a] Regular word reading accuracy, [b] Regular word reading speed.

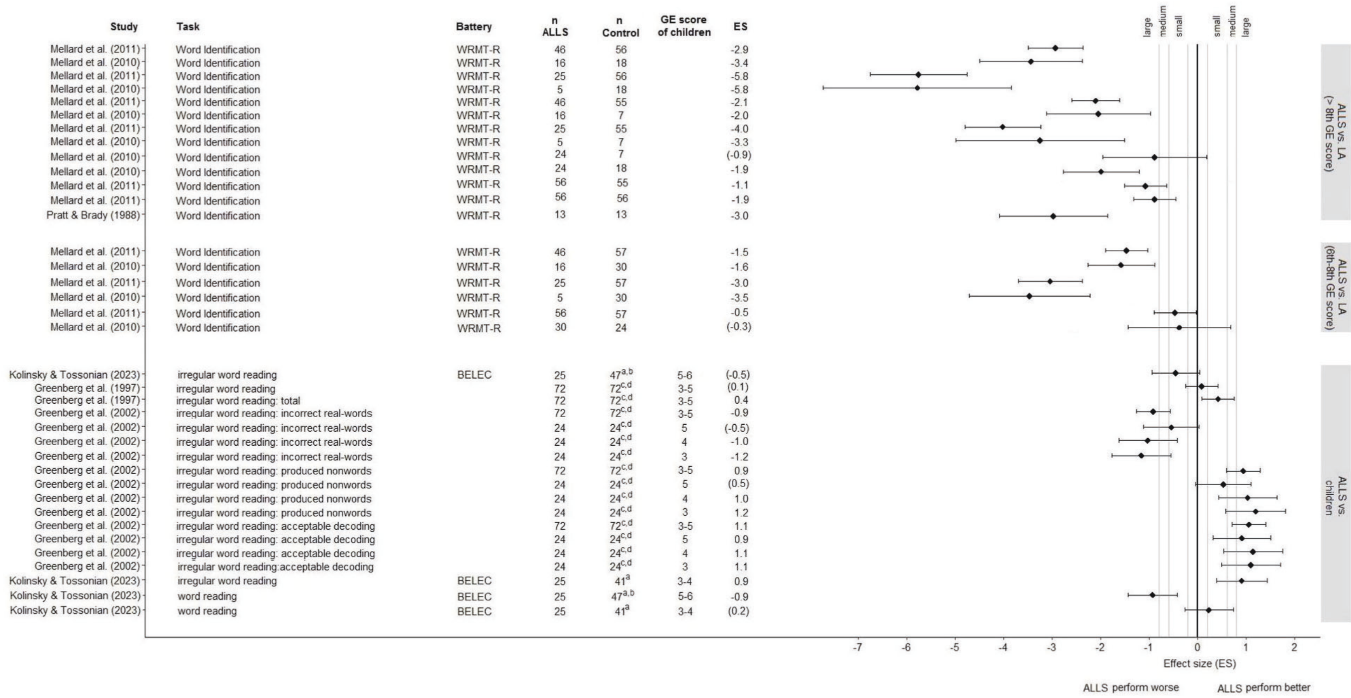

Fig. 4. Forest lot representing he bservations of word reading accuracy
Note. ES = effect size; *ALLS* = adults with low literacy skills; WRMT-R = Woodcock Reading Mastery Test–Revised (Woodcock, 1998); BELEC = Batterie d'évaluation du langage écrit e de ses troubles (Mousty et al., 1994). Consider hat we do report or display c mparisons f the matching variables.
Matching variable: [a] Regular word reading accuracy, [b] Regular word reading speed, [c] Word reading accuracy, [d] Decoding accuracy f seudowords.

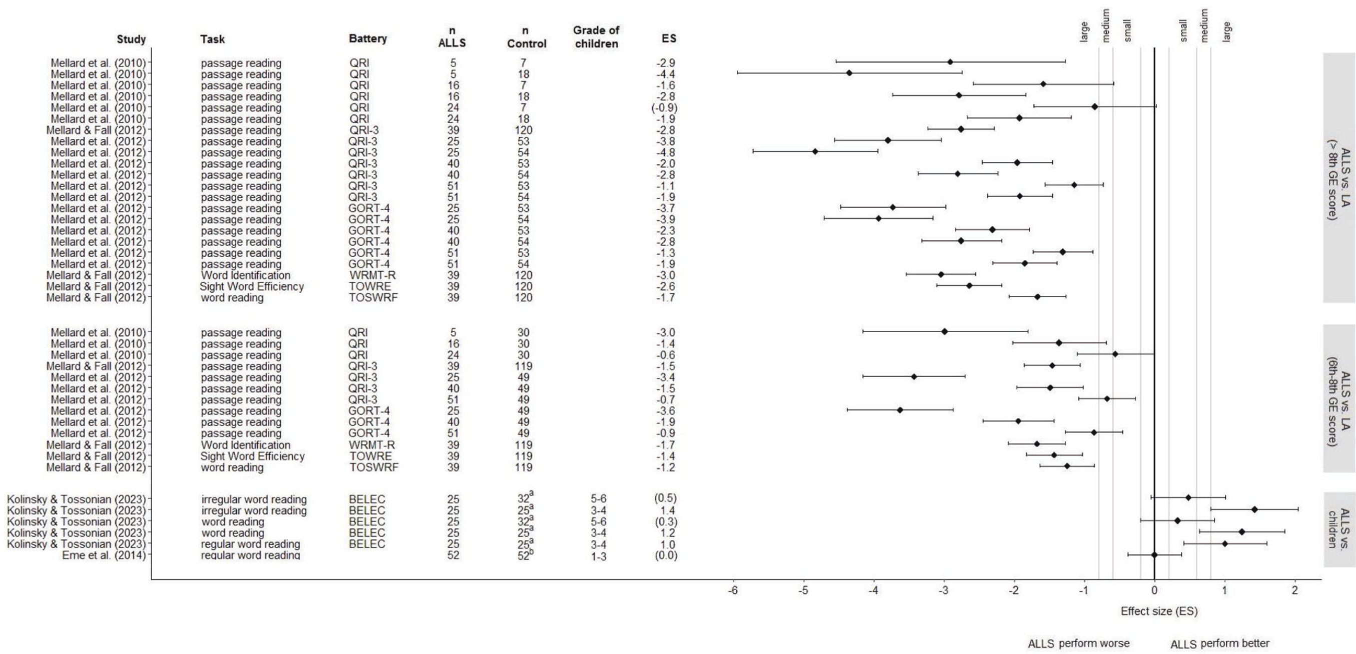

Fig. 5. Forest plots representing he bservations of word reading s eed
Note. ES = effect size; *ALLS* = adults with low literacy skills; QRI = Qualitative Reading Inventory (Leslie & Caldwell, 2001); GORT = Gray Oral Reading Tests (Wiederholt & Bryant, 2001); WRMT-R = Woodcock Reading Mastery Test–Revised (Woodcock, 1998); TOWRE = Test f Word Reading Efficiency (Torgesen and Wagner, 1999); TOSWRF = Test f Silent Word Reading Fluency (Mather et al., 2004); BELEC = Batterie d'évaluation du langage écrit e de ses roubles (Mousty et al., 1994). Consider hat we do report r display c mparisons f he matching variables.
Matching variable: [a] Word reading accuracy in Grade 3–4 and accuracy and speed in Grade 5–6, [b] Sentence comprehension (Mellard et al., 2012).

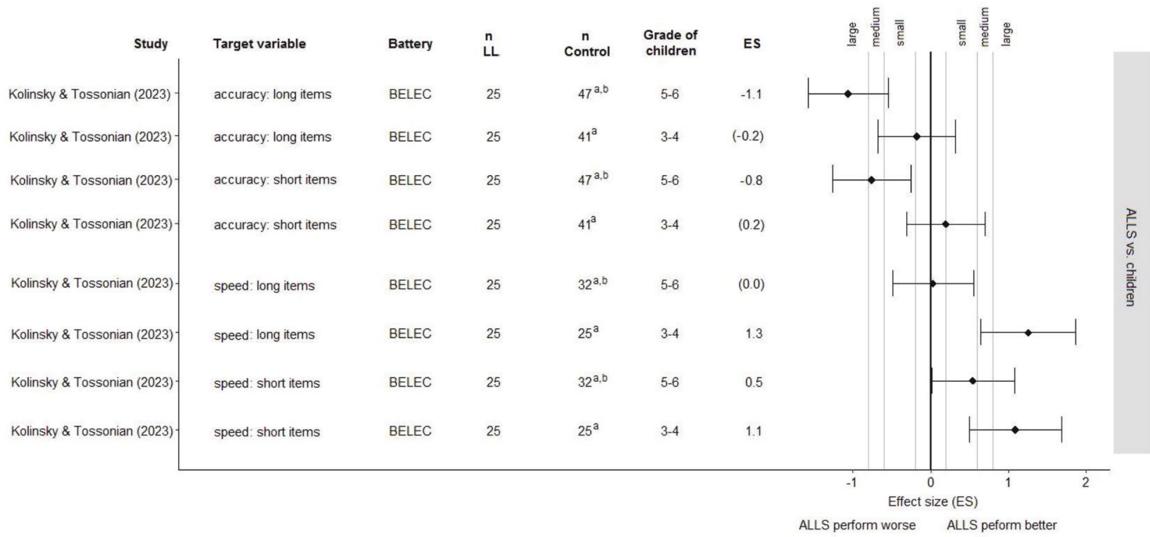

Fig. 6. Forest lot representing he bservations f other decoding measures
Note. ES = effect size; *ALLS* = adults with low literacy skills; BELEC = Batterie d'évaluation du langage écrit e de ses troubles (Mousty et al., 1994).
Matching variable: [a] Regular word reading accuracy, [b] Regular word reading speed.

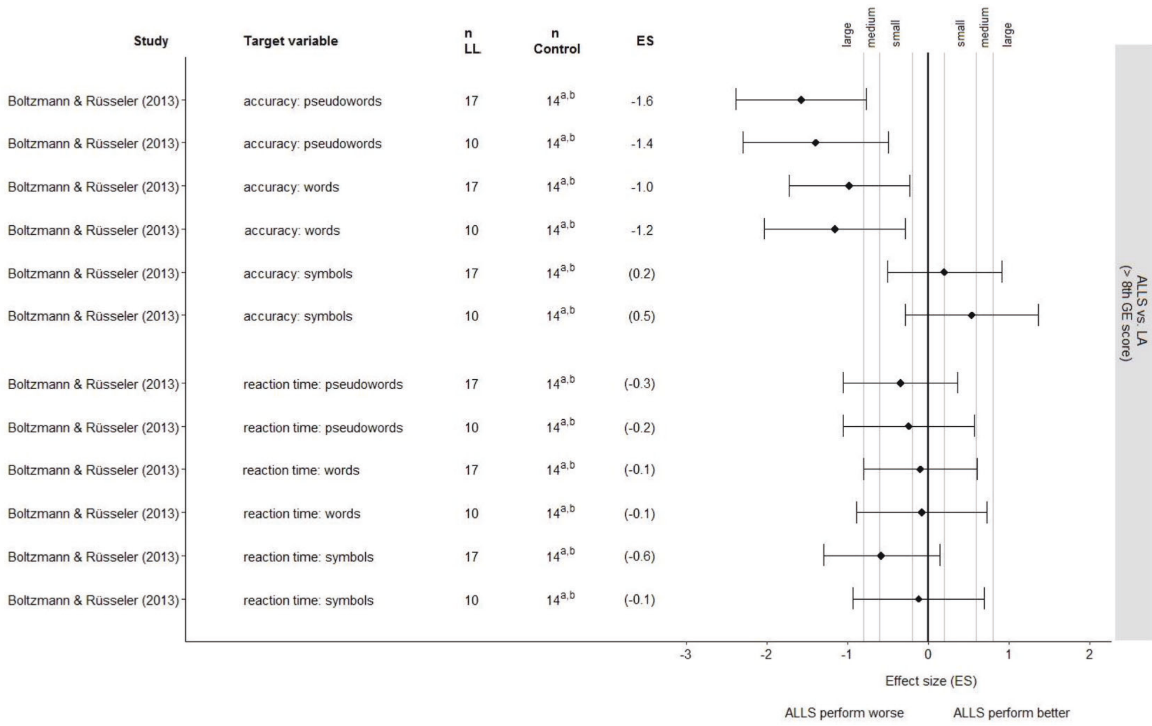

Fig. 7. Forest lot representing he bservations of an implicit reading ask
Note. ES = effect size; *ALLS* = adults with low literacy skills.
Matching variable: [a] Age, [b] Handedness.

3.3.1.1. Pseudoword decoding. Reading f seudowords is a d roxy f *phonological recoding*, i.e., the ability map graphemes into phonemes f llowing he alphabetic principle and c extual orthographic rules, hat allows c rrect decoding of any novel word r pseudoword. All studies assessed i via accuracy (Fig. 2) and speed measures (Fig. 3). ALLS showed lower pseudoword decoding skills (large very large effect sizes) han LA i speed, and in all except one study also in accuracy (Mellard et al., 2010). Relative reading-level matched children, ALLS were also less accurate in seudowo rd decoding, in all but e bservation (i.e., olinsky & Tossonian, 2023), with small large effect sizes, but were slower.

3.3.1.2. Word reading. Word reading was assessed with accuracy (Fig. 4) and speed measures (Fig. 5). As with seudoword decoding,

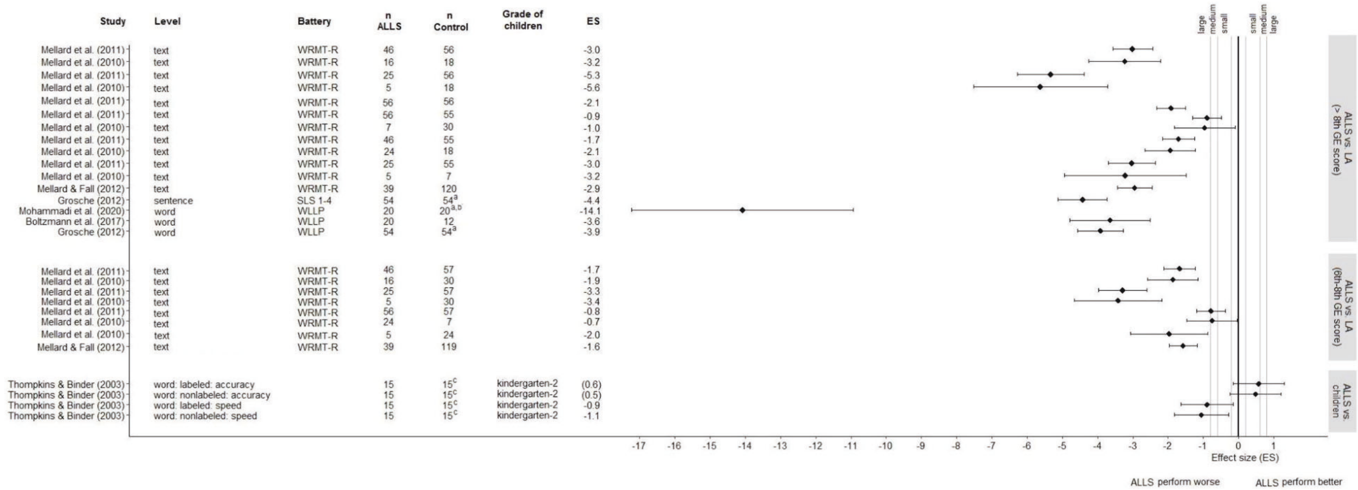

Fig. 8. Forest lot representing he bservations of reading c mprehension

Note. ES = effect size; *ALLS* = adults with low literacy skills; WRMT-R = Woodcock Reading Mastery Test–Revised (Woodcock, 1998); SLS 1–4 = Salzburger Lesescreening für die lassenstufen 1–4 (Mayringer & Wimmer, 2005); WLLP = Würzburger Leise Leseprobe (Küspert & Schneider, 1998). Consider hat we do report or display c mparisons f the matching variables. Matching variable: [a] Age, [b] Gender, [c] Reading composite score.

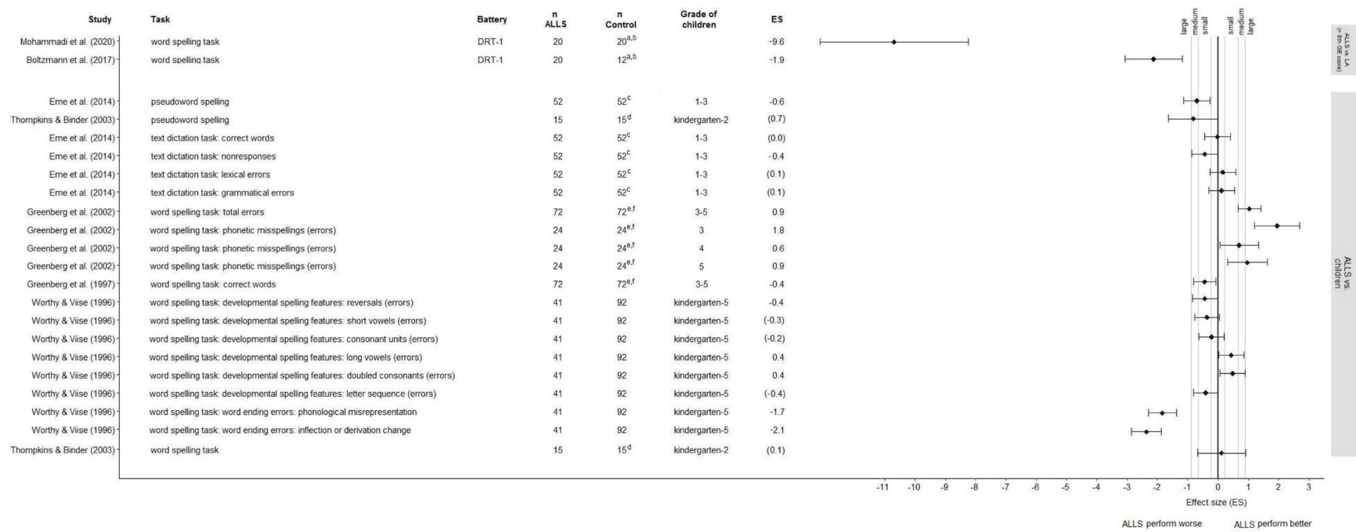

Fig. 9. Forest lot representing he bservations of spelling
Note. *ES* = effect size; *ALLS* = adults with low literacy skills; DRT-1 = Diagnostischer Rechtschreibtest für 1. Klassen (Müller, 2003).
Matching variable: [a] Age, [b] Gender, [c] Sentence reading c mprehension, [d] Reading composite score, [e] Word reading accuracy, [f] Decoding accuracy f seudowords.

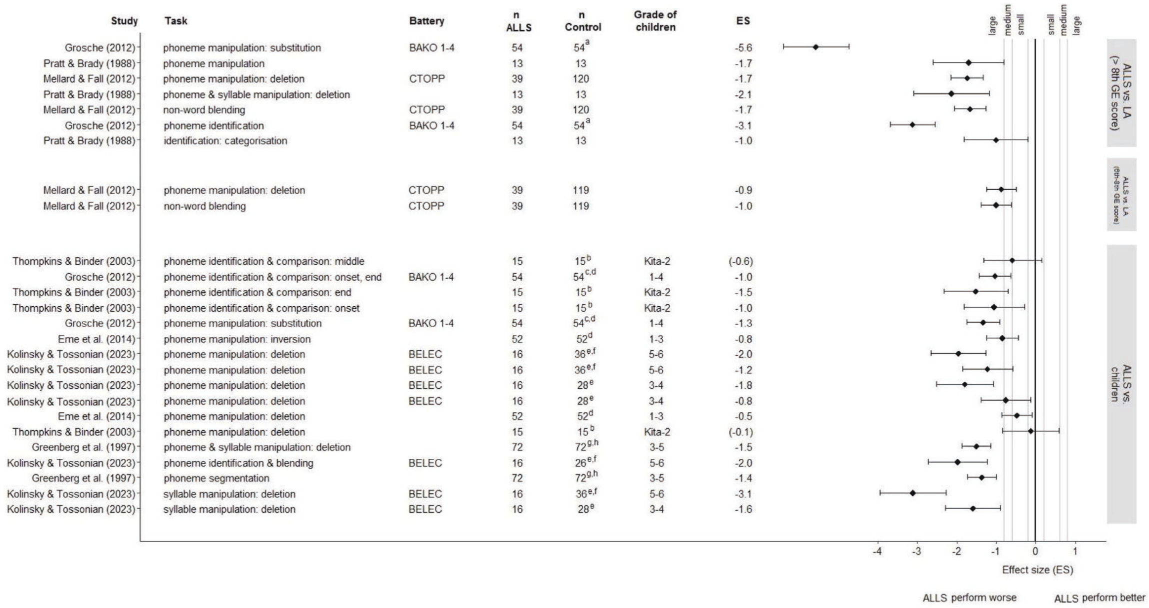

Fig. 10. Forest lot representing he bservations f phonological awareness
Note. ES refers = effect size; *ALLS* = adults with low literacy skills; BAKO 1–4 = Basiskompetenzen für Lese-Rechtschreibleistungen (Stock e al., 2003); CTOPP = Comprehensive Test of Phonological Processing (Wagner e al., 1999); BELEC = Batterie d'évaluation du langage écrit e de ses troubles (Mousty et al., 1994).
Matching variable: [a] Age, [b] Reading composite score, [c] Word reading c mprehension, [d] Sentence reading c mprehension, [e] Regular word reading accuracy, [f] Regular word reading speed, Word reading accuracy, [h] Decoding accuracy f seudowords.

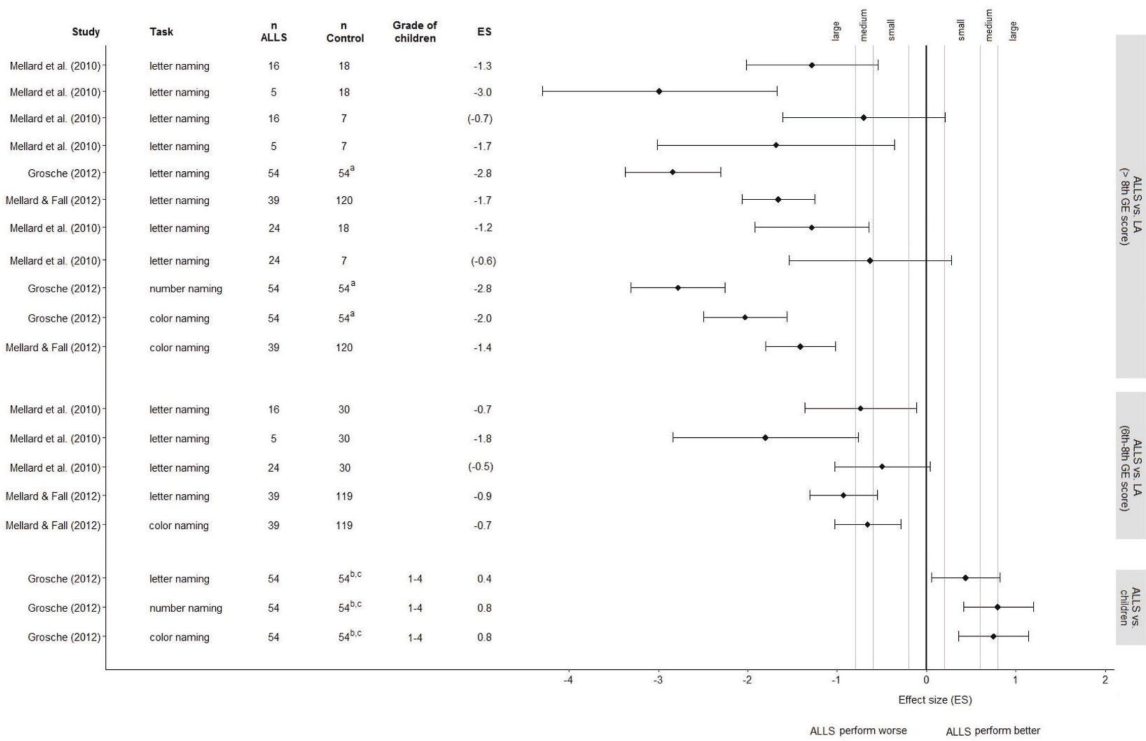

Fig. 11. Forest lot representing he bservations of RAN
Note. ES = effect size; *ALLS* = adults with low literacy skills.
Matching variable: [a] Age, [b] Word reading c mprehension, [c] Sentence reading c mprehension.

ALLS showed significantly lower word reading erformance han LA for both accuracy and speed, with medium very high effect sizes with he exception f a few single measures (Mellard et al., 2010, 2011). It is eworthy hat in Kolinsky and T ssonian (2023), although ALLS were matched in reading f regular words with children, hey were more accurate in irregular word reading han

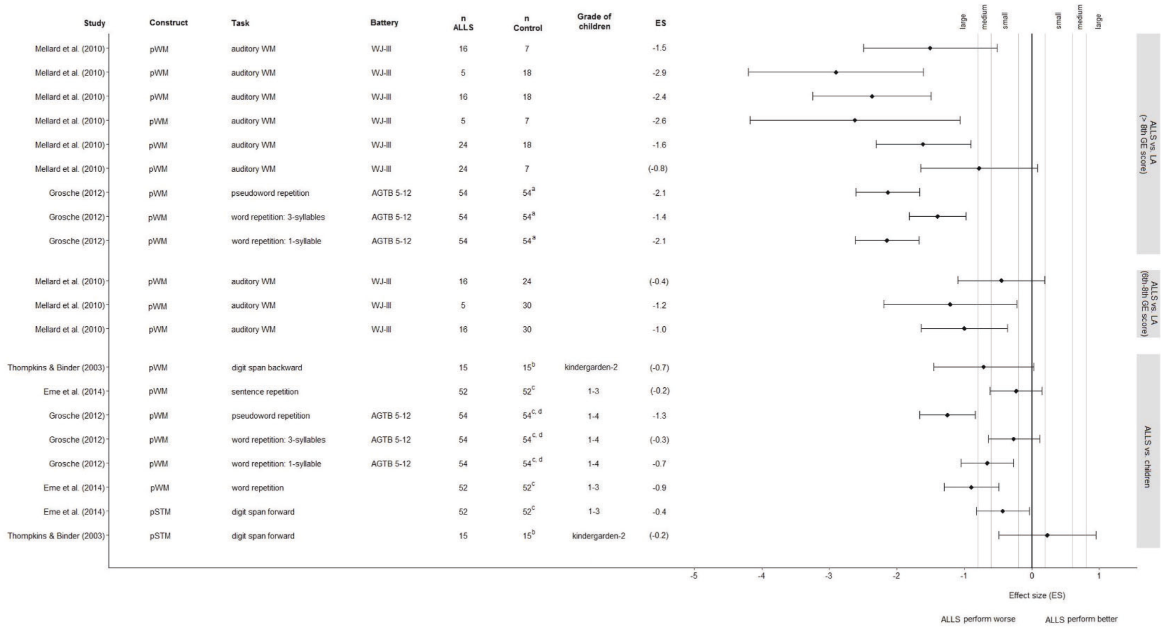

Fig. 12. Forest lot representing he bservations f pWM a d STM
Note. ES = effect size; *ALLS* = adults with low literacy skills; WJ-III = Woodcock-Johnson III Tests f Achievement (Mather & Woodcock, 2001); AGTB 5–12 = Arbeitsgedächtnistestbatterie für Kinder v 5 bis 12 Jahren (Hasselhorn e al., 2012).
Matching variable: [a] Age, [b] Reading composite score, [c] Sentence reading c mprehension, [d] Word reading c mprehension.

children from Grade 3–4 and were as accurate as children from Grade 5–6. Furthermore, i he study f Greenberg e al. (2002), a comparison f reading errors in irregular word reading showed that, whereas ALLS used rthographic rocessing strategies, children relied more phonological strategies. Thus, word reading errors by ALLS were more likely be real w rds han hose f children, who in contrast were more likely roduce nonword errors (decoding errors).

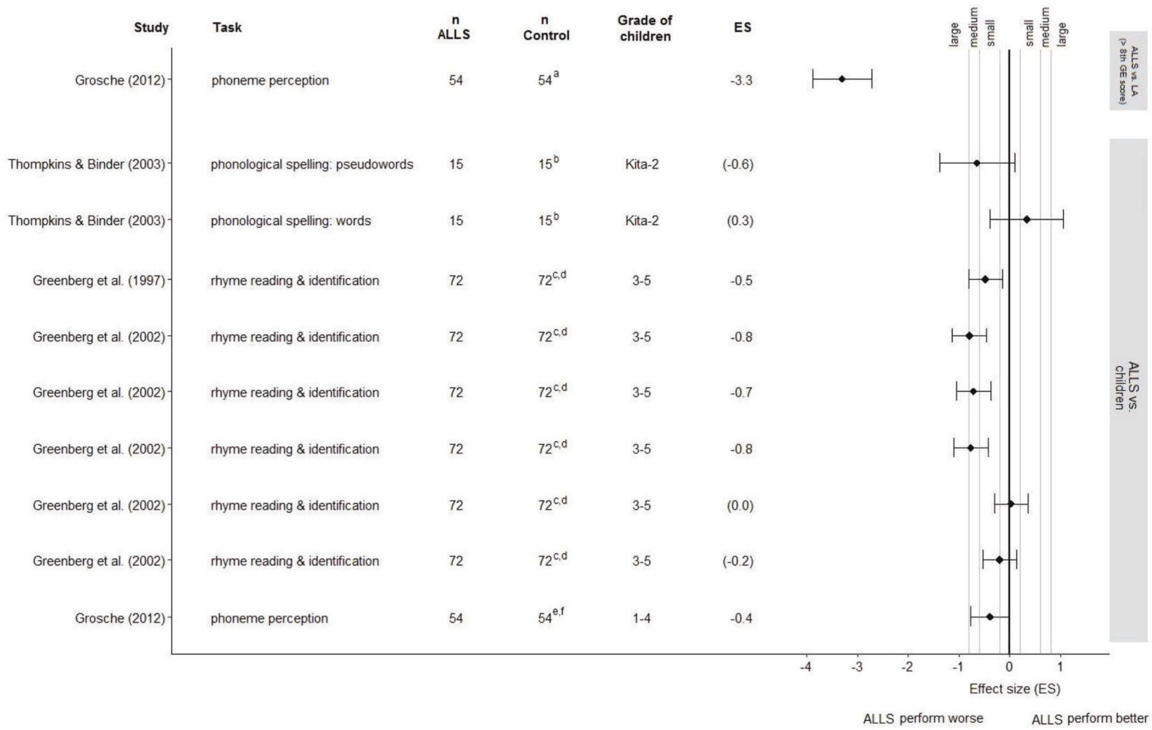

Fig. 13. Forest lot representing he bservations f her phonological measures
Note. ES = the effect size; *ALLS* = adults with low literacy skills.
Matching variable: [a] Age, [b] Reading c mposite score, [c] Word reading accuracy, [d] Decoding accuracy f seudowords, [e] Word reading c mprehension, [f] Sentence reading c mprehension.

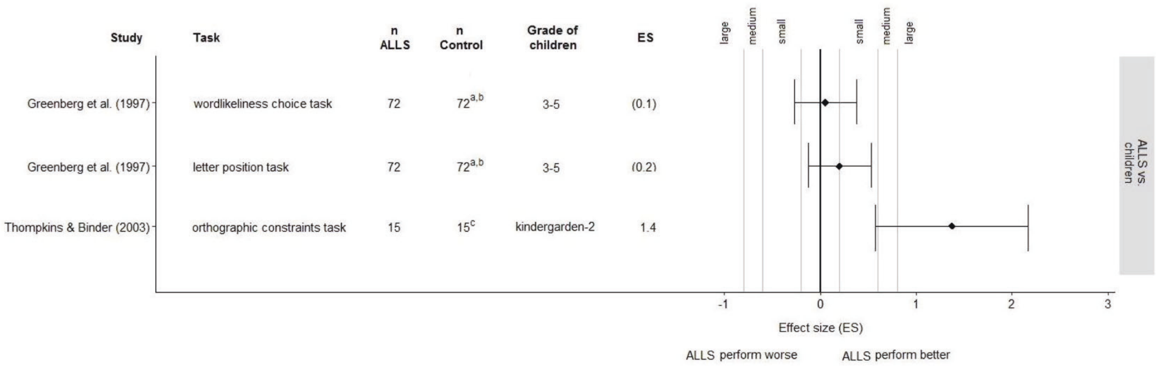

Fig. 14. Forest lot representing he bservations f orthographic knowledge
Note. ES = the effect size; *ALLS* = adults with low literacy skills.
Matching variable: [a] Word reading accuracy, [b] Decoding accuracy f seudowords, [c] Reading composite score.

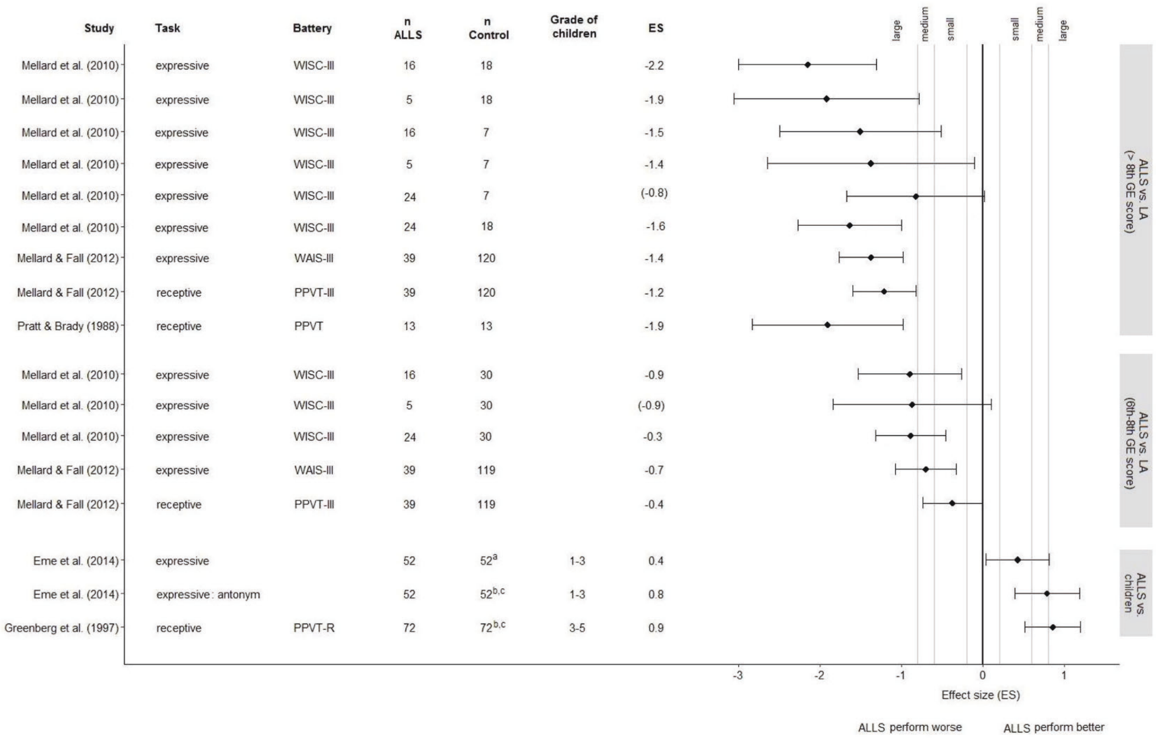

Fig. 15. Forest lot representing he bservations of vocabulary
Note. ES = effect size; *ALLS* = adults with low literacy skills; WISC-III and WAIS-III = the Wechsler Adult Intelligence Scale-III (Wechsler, 1997); PPVT = Peabody Picture Vocabulary Test (Dunn & Dunn, 1997).
Matching variable: [a] Sentence reading c mprehension, [b] Word reading accuracy, [c] Decoding accuracy f seudowords.

3.3.1.3. Other decoding measures. Decoding of combined material (words and seudowords: short vs. long) were assessed only by Kolinsky and T ssonian (2023), where ALLS were matched with children (Grade 3–4 a d 5–6) in regular word reading (Fig. 6). ALLS performed faster but as accurately as children from Grade 3–4 both short and long items. However, relative children from Grade 5–6, they were less accurate both short and long items, while only reading he short items faster.

In Boltzmann and Rüsseler (2013), articipants erformed a *implicit reading task*, i.e., a 1-back repetition ask of words, seudowords, and symbol strings, i which hey had indicate whenever a stimulus was repeated. B h roups f ALLS performed less accurately han LA words a d seudowords only, while here were roup speed differences for all s imuli types (Fig. 7).

3.3.1.4. Reading omprehension. ALLS performed w rse han LA reading c mprehension of words, sentences, a d text, in all bservations (Fig. 8). However, ALLS erformed c mparably reading-level matched children (with c mposite reading score as matching variable) in word reading c mprehension (Thompkins & Binder, 2003), but a speed/accuracy trade-off might have ccurred because ALLS read more slowly han the matched children.

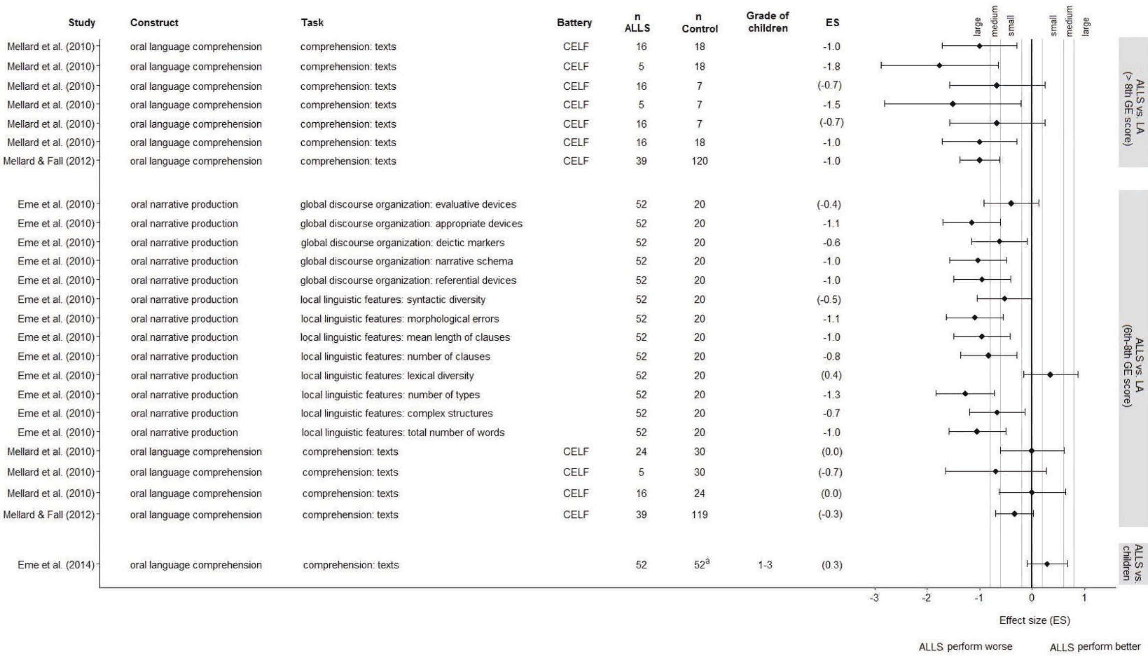

Fig. 16. Forest lot representing he bservations f oral language c mprehensio a d roduction
Note. ES = effect size; *ALLS* = adults with low literacy skills; CELF = Clinical Evaluation of Language Fundamentals (Semel e al., 1987). Matching variable: [a] Sentence reading c mprehension.

3.3.1.5. pelling. Spelling was assessed with seudoword, word, a d ext dictation tasks. The wo observations comparing ALLS and LA in word spelling showed hat ALLS perform worse (Fig. 9). When comparing ALLS with children, results seem inconsistent at he first glance, because depending he bservation, ALLS performed better, w rse r the same as children. However, results become systematic when differences i ype f task and errors (i.e., word vs. seudoword reading) between children and ALLS in honological and rthographic abilities are considered. C mpared reading-level matched children, ALLS performed c mparably r worse when spelling pseudowords (Eme e al., 2014; Thompkins & Binder, 2003), but produced fewer orthographic errors (due honetic similarity, *phonetic misspellings*, e.g., 'when' as 'wen'; Greenberg e al., 2002). In word spelling, ALLS erformed as similarly as reading-level matched children (Eme e al., 2014; Thompkins & Binder, 2003), while roducing fewer phonetic errors and m re non-phonetic errors[7] (e.g., 'squirrel' as 'chegh'; Greenberg e al., 2002). In addition, hey produced more lexical errors han children, i. e., misspelling a certain word as a her phonetically similar but semantically different one (e.g., 'fortunate' as 'force'; Greenberg et al., 2002). Also, c mpared children (without a reading-level match), ALLS made m re honological misrepresentations (e.g., 'such' as 'sudden', 'scratch' as 'se-') and i flection or derivation change errors (e.g., 'batting' as 'bat', 'plain' as 'planning'), indicating rer phonological decoding skill. However, hey produced fewer errors in long vowels and consonant doubling errors (Worthy & Viise, 1996), showing better rthographic knowledge.

In sum, these results suggest hat in comparison reading-level matched children, ALLS may have rer honological rocessing skills and heir spelling seems rely less honological, and more r thographic strategies. I addition, particular morphological difficulties in word endings seem be a specific deficit when ALLS are compared children in general (inflection or derivation change; Worthy & Viise, 1996).

3.3.2. Information processing level

From the 22 studies with measures different cognitive functions (Table S5), 17 compared he erformance f ALLS with hat f typically developing children or LA. Eight ther studies (Bar-Kochva et al., 2021; Greenberg e al., 1997; 2009, 2011; Talwar et al., 2018; Nanda e al., 2010; Eme e al., 2010; 2014) reported correlations between cognitive functions (i.e., information rocessing level) and reading components and spelling (i.e., skill level; see Table S5). Three ther studies encompass a c mparison between native and non-native speaking ALLS. I m st f he studies, different facets f hon logical rocessing were assessed (Figs. 10–13). Orthographic knowledge, vocabulary, ral language c mprehension and roduction, speech rocessing, and i elligence were also assessed by several studies (Figs. 14–16), while ther cognitive measures were only examined by single studies (Fig. 17).

3.3.2.1. Phonological awareness (PA). The metalinguistic awareness hat allows analyze and manipulate sounds f s ken language, was assessed with identification, segmentation, blending and manipulati tasks (Fig. 10). ALLS performed w rse han children and

[7] No effect sizes for non-phonetic errors and honological misrepresentations are reported i Table 9 because mean and standard deviations were reported f r these error types in Greenberg e al. (2002).

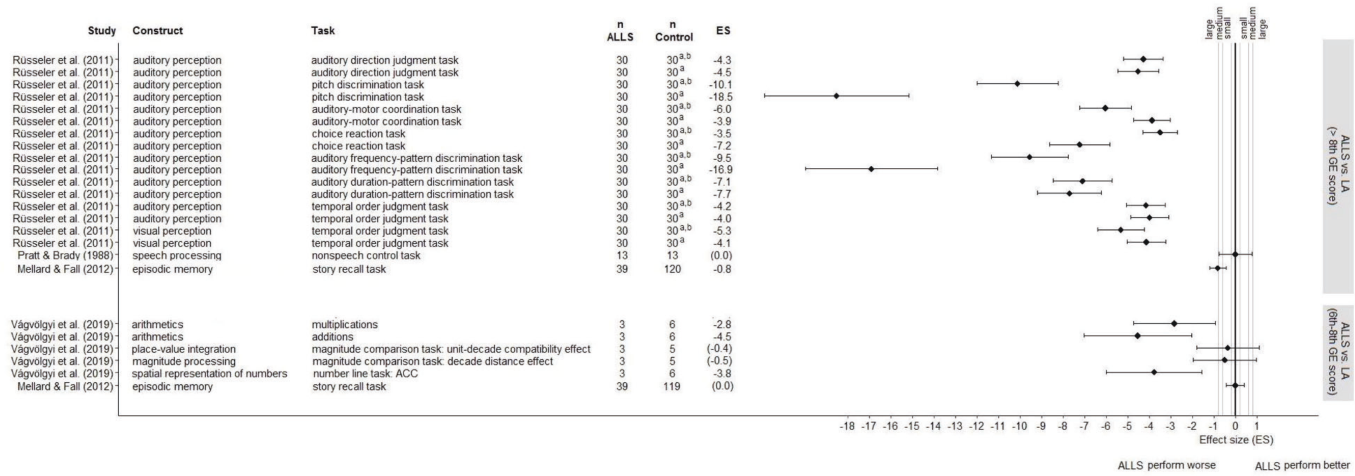

Fig. 17. Forest lot representing he bservations f other cognitive functions
Note. ES = effect size; *ALLS* = adults with low literacy skills.
Matching variable: [a] Age, [b] IQ.

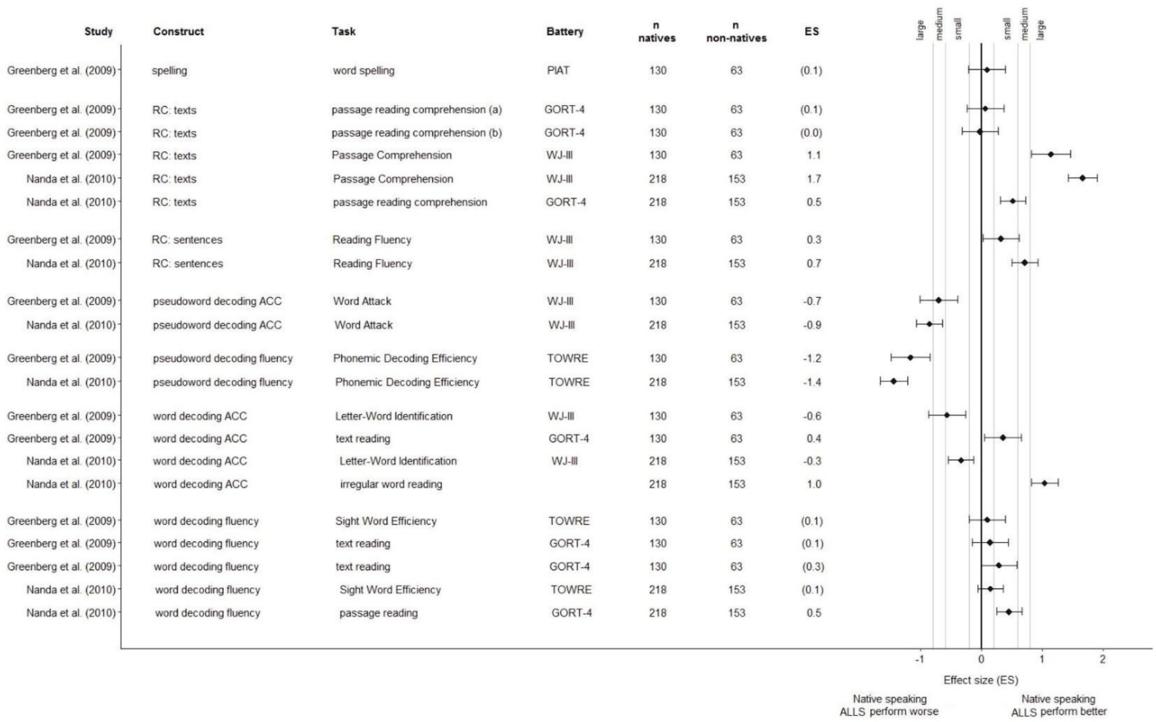

Fig. 18. Forest lot representing he differences between English native and - native speaking ALLS the skill level
Note. ES = effect size; *ALLS* = adults with low literacy skills; RC = reading c mprehension; ACC = accuracy; PIAT = Peabody I dividual Achievement Test (Frederick & Markwardt, 1997); GORT = Gray Oral Reading Tests (Wiederholt & Bryant, 2001); WJ-III = Woodcock-Johnson III: Tests f Achievement (Woodcock et al., 2001); TOWRE = Test of Word Reading Efficiency (Torgesen and Wagner, 1999).

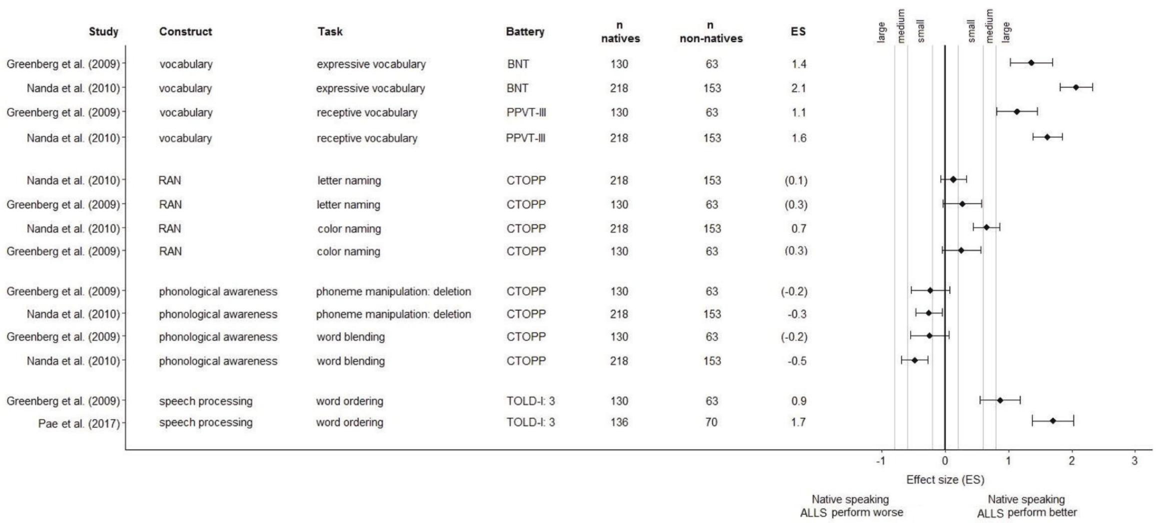

Fig. 19. Forest lot representing he differences between English native and - native speaking ALLS the i formation rocessing level
Note. ES = effect size; *ALLS* = adults with low literacy skills; BNT = Boston Naming Test (Kaplan et al., 2001); PPVT-III = Peabody Picture V - cabulary Test (Dunn & Dunn, 1997); CTOPP Comprehensive Test of Phonological Processing (Wagner e al., 1999); TOLD-I = Test of Language Development-Intermediate (Hammill & Newcomer, 1997).

LA in all but wo bservations, he latter both i c mparison children (kindergarden Grade 2; Thompkins & Binder, 2003). Due the heterogeneity f hese studies, i was ssible isolate factors moderating the effect sizes (e.g., orthography, reading level, age f the children).

3.3.2.2. Rapid automatic naming (RAN). The ability ame a set f visually presented stimuli aloud as fast as ossible is a i dicator of retrieval efficiency f phonological representations from long-term memory. RAN was assessed by aming letters, umbers, and colors (Fig. 11). ALLS performed better han children for all materials, but hey performed worse han LA (except hree bservations f Mellard et al., 2010). The larger he literacy ap (in GE scores) between ALLS and he reference groups is, the larger are the effect sizes for RAN: The effect sizes are larger i c mparison LA with GE score above 8th compared LA with 6 h 8th GE score. These effect sizes c uld be explained by stimulus i em type (letters, umbers, colors); thus, s imulus type c uld be isolated as a moderator.

3.3.2.3. Phonological short-term memory (pSTM). The ability store and maintain honologically coded i formation for a brief eriod f time was assessed with verbal recall f digits. ALLS performed w rse ha children in e bservation (kindergarten Grade 3; Eme et al., 2014), while difference was found in another bservation (Thompkins & Binder, 2003, Fig. 12).

3.3.2.4. Phonological WM (pWM). The ability simultaneously store, maintain, and manipulate phonological information for a brief eriod f time, was assessed with recall and manipulation of syllables, seudowords, words, sentences, and digits (Fig. 12). ALLS performed w rse han children in asks of repetition of words, pseudowords, or a list f one-syllable words. However, difference was found between groups when he task required repeating sentences f increasing length a d of syntactic complexity, repeating a list f three-syllable w rds r of digits in reverse rder.

Mellard et al. (2010) split he participants into six roups according heir literacy levels: hree fitting our definition of ALLS (one with below 2nd, one with 2 d 4th a d one with 4 h 6th GE scores) and hree fitting LA (one with 6 h 8th, one with 8 h 10th a d one with 10th 12th GE scores). This study did rovide roup c mparisons. Based he iven raw data, we conducted a secondary analysis, which showed lower erformances of ALLS compared LA except for wo observations (Mellard et al., 2010). The effect sizes are larger i c mparison LA with GE score above 8th compared LA with 6 h 8th GE score.

3.3.2.5. Other phonological measures. The single study (Grosche, 2012) assessing *phoneme perception,* i.e., he ability identify he smallest units f s ken language, found hat ALLS perform w rse han reading-level matched children and age-matched LA with stronger effect sizes when compared with adults, as expected (Fig. 13).

In studies f Greenberg e al. (1997, 2002) and Thompkins & Binder (2003) combined measures were assessed, i.e., measures reflecting a mixture f honological rocessing and literacy skill tasks (combination of information rocessing and skill level). These asks were honological spelling f words a d words and rhyme reading a d identification. In a *phonological spelling task* (Thompkins & Binder, 2003) hat required articipants spell words a d seudowords rally, ALLS erformed as well as reading-level matched children (Fig. 13). The *rhyme word reading task* f Greenberg e al. (1997, 2002) required articipants read wo w rds, identify heir phonemes, and make a decision whether they rhyme r . ALLS erformed verall worse han reading-level matched children (Grade 3–5; in total score; Greenberg e al., 1997, 2002). Interestingly, ALLS performed w rse han reading-level matched children, ly rhyming w rds (but for -rhyming es), re ardless whether he rhyming words were rtho-graphically similar (e.g., barge – large) or different (e.g., fuel – mule). It is worth mentioning hat ALLS erformed w rst in he orthographically different rhyming word condition, whereas children performed w rst in he rthographically similar -rhyming word condition (e.g., have – gave). The authors c cluded hat ALLS rely less phonological strategies when encountering diffi-culties compared children.

3.3.2.6. Orthographic knowledge. The i formation stored in long erm memory hat enables e represent sp ken language i written form was assessed with hree orthographically challenging tasks (Fig. 14). In he *word-likeness choice task* (Greenberg e al., 1997) a d he *orthographic onstraints task* (Thompkins & Binder, 2003), articipants had choose a seudoword (within a

Table 1
General a d non-verbal intelligence f ALLS.

Study	Task	*MS*	*D*
Boltzmann e al. (2011)	CFT	84	reported
Rüsseler e al. (2011) (group 1)	CFT	92.8	7.1
Rüsseler e al. (2011) (group 2)	CFT	83.3	6.3
Rüsseler e al. (2013)	CFT	86.7	7.4
Boltzmann & Rüsseler (2013)	CFT	90.1	12.2
Eme e al. (2010)	CFT	69% f he roup perform between 11th and 20th ercentile score	
Grosche (2012)	ZVT	77	15
Vágvölgyi e al. (2019)	LPS-2	59.4	1.6
Bar-Kochva et al. (2021)	LPS-2	90.72	9.59
Pratt & Brady (1988)	RPM	98.7 (PR 46.62)	
Mellard et al. (2011) (group 1)	WAIS-III	72.2	9.7
Mellard et al. (2011) (group 2)	WAIS-III	72.2	6.6
Mellard et al. (2011) (group 3)	WAIS-III	78.1	11.1

Note. Pratt & Brady (1988) reported the i elligence f heir participants as percentile (PR) score hat was converted. SDs cannot be converted, therefore, i is reported.
Eme e al. (2010) reported the i elligence f heir participants as percentile score.
CFT = Culture Fair Test (Cattell, 1974; Weiβ, 1998); ZVT = Number-Connection-Test (Oswald & Roth, 1978); LPS-2 = Leistungsprüfsystem 2 (Kreuzpointner e al., 2013); WAIS-III = Wechsler Adult Intelligence Scale (Wechsler, 1997); RPM = Raven's Progressive Matrices est (Raven e al., 1976).

seudoword air) hat was more “word-like”, a d hus, decide which one confirmed and which one violated s andard E lish orthography. The *letter position task* assessed rthographic knowledge i volving spatial redundancy (see Greenberg e al., 1997,p . 266). I he word-likeness choice and in the letter sition asks, differences were found between ALLS and reading-level matched children (Greenberg e al., 1997), while i he orthographic constraints ask (Thompkins & Binder, 2003), ALLS performed better han reading-level matched children (kindergarten Grade 2).

3.3.2.7. Vocabulary. The ability u derstand he meaning f words and use them correctly, was assessed with receptive and expressive vocabulary. In both, ALLS performed significantly better han reading-level matched children (Grade 1–5), but w rse han LA with he exception f wo observations (Mellard et al., 2010, Fig. 15). As already shown for RAN and WM results (Figs. 11 and 12), an increase in the literacy ap between ALLS and he reference roups end lead towards larger effect sizes.

3.3.2.8. Oral language comprehension and production. In regards he ability understand s ken language, ALLS performed w rse han LA with a reading level above 8 h GE score with he exception f wo observations (Mellard et al., 2010), but similarly children and LA with a reading level of 6th 8 h GE score (Fig. 16). This suggests hat ral c mprehension difficulties in ALLS are less ronounced han hose f written language (i.e., reading comprehension, see Fig. 8).

Another linguistic competence, i.e., ral arrative production, was assessed i one study (Eme e al., 2010). ALLS performed w rse han LA local linguistic features (e.g., morphological errors, lexical variety, syntactic variety) and global discourse rganization (i.e., evaluative means, referential means) en f 13 measures (6th 8 h GE sc res; Fig. 16).

3.3.2.9. Other ognitive functions. This category refers single studies and/or single bservations only. ALLS showed lower erformance i auditory a d visual erception (Rüsseler e al., 2011), episodic memory (Mellard & Fall 2012), and artially in some mathematical skills (Vágvölgyi e al., 2019) c mpared LA (Fig. 17).

3.3.2.10. Intelligence. In ests f non-verbal fluid and eneral intelligence measuring abstract reasoning, ALLS reached below average r very r standard values i half f he bservations (Table 1). Note, h wever, hat i elligence is a loosely defined c cept (Finkelstein, 2003; Gustafson & Samuelsson, 1999) a d hat he ests used in the different studies measure various specific aspects f cognitive ability hat may depend varying degrees cultural and educational aspects. Furthermore, i some studies an IQ wo standard deviations below the mean was an exclusion criterion for ALLS (e. ., Boltzmann e al., 2017; Boltzmann, Rüsseler, 2013; Mohammadi et al., 2020).

3.3.3. Skill and nformation processing levels in native versus non-native speaking ALLS

We excluded from he resent systematic review studies with second language learners (i.e., people still learning he language f testing) but those studies with second language speakers (i.e., -n ative speakers who are therwise fluent in he esting language). Some studies included mixed ALLS groups (i.e., with b h ative and non-native speakers), because, in ractice, hey are ften mixed i adult basic education classes. Among the 27 s udies the cognitive rofile of ALLS, seven rovided i formation about he language background f he articipants, four included a mixed ALLS roup , 13 i cluded ative speakers only, a d three c mpared native (English) a d non-native speaking ALLS. These latter hree studies, compared he erformance f he wo roups a he information rocessing level a d wo f hem additionally at the skill level.

In these studies, b h roups had word reading skills between 3rd and 5th GE score i he language f instruction. At the skill level (Fig. 18), native speaking ALLS performed equally well r better han non-native s eaking ALLS in word reading speed, sentence, and ext comprehension and s elling. In contrast, ative speaking ALLS erfo rmed w rse in seudoword decoding han -native speaking ones both i speed and accuracy.

At the i formation rocessing level (Fig. 19), native speaking ALLS performed equally well r better han non-native s eaking ALLS in vocabulary and speech processing. Native speakers also erformed equally well r better i PA, while hey performed equally well r better han non-native speakers i RAN.

3.3.4. Neurobiological level

The eurobiological characteristics f ALLS are mostly unstudied. I hree studies from the same research roup, eural c rrelates of brain structures and eural activation were examined in ALLS and LA usin electroencephalography (EEG), and structural and functional magnetic resonance imaging (MRI and fMRI).

In an EEG study, Boltzmann and Rüsseler (2013) investigated event-related otentials (ERPs) while ALLS and LA erformed a 1-back repetition ask letter strings (words and seudowords) and symbol strings, rior and after four months of intense literacy training. In line with previous literature (e.g., Maurer et al., 2006; for a recent review, see, e.g., Amora e al., 2022), a larger egative peak for letters compared non-letters at ~170 ms after s imulus set, he *N170* (captured by he left-lateralized ccipito-temporal electrodes) was found i b h roups, which is europhysiological marker f rint expertise and develops i he early years of reading acquisition (e.g., Maurer et al., 2006). Interestingly, after a 4-month literacy raining, the difference in this left-lateralized N170 increased significantly due more negativity for letter strings relative pre-training, while significant re-post raining difference was found for symbol strings. The N170 for letter strings was also correlated with he reading improvement induced by raining.

In another study, Boltzmann e al. (2017) found lower gray matter intensity i ALLS relative LA (matched in age, sex, and verbal IQ) in supramarginal gyrus (bilateral), i a ular yrus (bilateral), i he precuneus (bilateral), i he superior arietal lobule (bilateral), and in the left arietal operculum. All f these regions are involved in honological rocessing (see Vandermosten et al., 2012). No brain region showed larger gray matter intensity in ALLS han LA. Interestingly, hese structural brain differences were longer found after literacy training, and hence, hey seem depend reading experience. Furthermore, using diffusion ensor imaging, Boltzman et al. examined differences i fractional anisotropy (FA) investigate whether he eculiarity in the anterior a d posterior language regions found i previous studies with ALLS and children with DD could be consequence f a disconnection between temporal-parietal and frontal language regions (for a review, see Peterson & Pennington, 2012). The only brain region with significantly reduced FA i ALLS was he left enu f the corpus callosum, suggesti impaired quality f white matter i his region. The corpus callosum harbors myelinated fibers serving information transfer between the left and he right hemisphere f he brain. FA values increased after raining, so hat there was longer a difference c mpared LA. Thus, functional connectivity in ALLS was aligned with he connectivity f the LA after raining.

Mohammadi et al. (2020) investigated resting-state connectivity in ALLS vs. LA with fMRI rior and after a literacy raining. There were significant roup differences between ALLS and LA, even when reading was required, rior training, in connectivity in three resting-state networks: a left fronto-parietal network, a visual etwork, and a etwork involving he basal anglia (basal anglia etwork). Importantly, intensive literacy raining resulted in changes i resting-state connectivity (i.e., partially closer hat of LA) in st-training ALLS which correlated with reading improvements.

4. iscussion

In this review, we systematically collected, categorized and summarized the research assessing the c itive rofiles f ALLS, using age, education, and reading level as criteria. Cognitive measures f the 27 resulting studies were categorized according hree levels f he *Multi-level framework of Developmental Dyslexia* f Lachmann and Bergström (2023): he skill level (20 studies; see Figs. 2–9 and Table S2), the i formation rocessing level (22 studies; see Figs. 10–19 and Table 1 and S3), and he neurobiological level (hree studies). We considered studies independent f roup matching, i.e., hose with and without age- and/or reading-level matched designs. These studies were hus rouped according he assessed c struc ts rather han methodological aspects. I should be ed hat for s me f he assessed c structs, only a small umber of studies, s me with very small sample sizes, could be identified (see Tables S2–3 for verviews). In articular, he results for implicit reading (Fig. 7), other decoding measures (Fig. 6), pSTM (Fig. 12), and orthographic knowledge (Fig. 14) should be interpreted with caution, even though some studies used multiple tasks and/or measures assess the same c struct or included different c mparison roups.

To learn about he otential association between low literacy in adulthood a d the research DD, we discuss he potential link between the identified rofiles f ALLS and hose found i DD research.

4.1. Skill level

The utcome hat ALLS perform w rse han LA in most reading and spelling measures is hardly surprising and was expected. These results confirm and validate the low literacy skills of ALLS and highlight hat heir difficulties are selectively restricted certain literacy (sub)skills, but encompass all measures a he skill level, yet with varying severity. Moreover, all reading measures c rrelated with each other, except reading c mprehension (see Table S4). The absence of correlations between reading c mprehension and he other reading measures i s me bservations might indicate a reater influence f oral comprehension in the respective samples. This is in line with he Simple View of Reading (Gough & Tunmer, 1986; Joshi, 2018; see als Nation, 2019) which roposes hat besides decoding, oral comprehension is additionally involved in reading comprehension. A closer look at Table S4 also suggests hat his attern might be he result of an interaction between he ransparency f rthography (more ransparent German vs. opaque English) and what (sub)skill (e.g., seudoword decoding, word reading) was perationalized with which measure (accuracy vs. s eed).

From the results f those few studies applying reading-level matched designs (Eme e al., 2014; Greenberg e al., 1997, 2002; Grosche, 2012; olinsky & Tossonian, 2023; Thompkins & Binder, 2003), it can be inferred hat, when reading, ALLS rely more orthographic strategies han decoding. This may explain why ALLS were less accurate in seudoword decoding despite being matched with children in regular-word reading (olinsky & Tossonian, 2023; for a discussion methodological limitations see Van den Broeck & Geudens, 2012; Zoccolotti, 2020). The equally or faster speed in pseudoword decoding of ALLS relative children could be due enerally faster rocessing speed in adults (e.g., Luna e al., 2004). That ALLS rely more orthographic strategies and less phonological strategies is also reflected i he ype f errors found in reading and spelling. Their reading errors resulted more likely in other real words (Greenberg e al., 2002). In contrast, children's reading errors were m re ften decoding errors and hus, they were more likely roduce nonwords. Regarding spelling, ALLS performed similarly r w rse han children when spelling seudowords (Eme e al., 2014; Thompkins & Binder, 2003). However, when spelling words, they made fewer orthographic errors and more s elling errors resulting i ther words (Greenberg e al., 2002), and hence, c firming hat they rely more orthographic strategies given hat heir orthographic knowledge is as good as or even better han hat f children.

The results f the few studies (Greenberg e al., 2009; Nanda e al., 2010; Pae e al., 2017) c mparing native and -native speaking ALLS show hat while ative speaking ALLS have roblems i decodi skills (grapheme-phoneme conversion), i.e., in using he phonological (sublexical) r ute, he roblems f non-native speaking ALLS are more likely be due lower language abilities (i.e., vocabulary and speech processing, see ext section). This is expressed i heir worse erformance i word reading speed, sentence and ext c mprehension (and spelling) compared ative s eaki ALLS.

Comparing his profile for ALLS at skill level with hat k wn from he literature DD, a similar attern of deficits can be bserved (for meta-analyses see, e.g., Georgiou et al., 2022; Kudo, Lussier, & Swanson, 2015; Parrila et al., 2020). Children and adolescents with

DD performed w rse han heir peers without DD in different measures f literacy skills, especially in pseudoword decoding, but also i word reading, reading comprehension, and spelling. Even hough the resul s f our comparisons at the skill level between ALLS and children (both reading-level matched and -matched groups) were i con sistent (see Figs. 2–8), the reading skills of ALLS seem be closer hose f primary school children han of LA.

4.2. Information processing level

In erms f the i formation rocessing level, ALLS showed worse erformance compared LA i almost all cognitive recursor functions, i.e., PA, RAN, WM, honeme perception, and f r her honolog ical measures, while in orthographic knowledge. Also, the larger he difference in reading skills between ALLS and LA, the larger are he effect sizes for RAN, WM, and vocabulary. Thus, effect sizes were larger when ALLS were c mpared LA with better reading skills (>8th GE) han with lower reading skills (6th-8th GE score), reflecting the association between reading skills and examined co itive processes (see, e.g., Lachmann & Bergström, 2023). Consistent with ther findings (e.g., Melby-Lervåg et al., 2012), correlations between measures at skill and information rocessing levels were found (see Table S5), although it was ssible identify clear atterns f ossible moderators f he effect sizes (e.g., ransparency f he rthography). This may be due he reat variability of constructs a d rthographies the studies considered.

When interpreting these results, he reciprocal relationship between cognitive functions and literacy skills must be considered (see Huettig, Lachmann et al., 2018; Lachmann & Bergström, 2023). For example, only vocabulary influences reading skills, but reading skills (and related PA abilities) and reading experience also influence vocabulary acquisition (e.g., nerding e al., 2020; for further explanation, see, Huettig, Lachmann et al., 2018). To understand he reciprocal influence of cognitive functions (e.g., PA) and literacy, he processes involved in literacy acquisition must be considered. Durin he literacy-specific procedural learning process initiated by instruction, re-existing c itive functions (memory, motor, and language abilities) are recruited, modified a d coordinated establish literacy specific c itive procedures (i.e., reading, spelli ; Lachmann, 2002, 2018; Lachmann & van Leeuwen, 2014). Through a prolonged and intense raining, hese rocedures hen become automated (Froyen et al., 2009; Lachmann & van Leeuwen, 2008; Nicolson & Fawcett, 2007, 2018). According he rinciples f a feedback loop, he acquisition f literacy skills reciprocally affects he re-existing cognitive functions recruited he literacy-specific procedure (e.g., PA, RAN, WM, and visual information processing; see, e.g., Huettig, Lachmann et al., 2018; Lachmann & Bergström, 2023, for reviews). For instance (in alphabetic r-hographies), PA is required f r he acquisition f rapheme-phoneme correspondences, but he increasing acquisition and he associated rowing i sight into the segmental structure f words contribute substantially the improvement of PA (see Lachmann & Bergström, 2023). Furthermore, more c mplex honological rocessing abilities, such as phoneme awareness, may only develop as a consequence f literacy acquisition (see Landerl et al., 2019; Peterson et al., 2018). Indeed, his possibility is supported by the results found a eurobiological level, especially those regarding the effects f raining programs, by showing hat re-training differences between ALLS and LA diminished or were longer found after raining (Boltzmann e al., 2017; Boltzmann and Rüsseler, 2013). Thus, ALLS' lower performance i cognitive functions tasks could be ly the cause but also he consequence f low reading experience and he resulting weak literacy skills.

The c mparison between ALLS and reading-level matched children is of utmost importance. Note, however, hat iven our main goal, we did exclusively consider studies with his design, which is ecessary ffer the c mplete icture f cognitive functions in ALLS. We f und hat ALLS performed consistently worse han reading-level matched children in PA only, but better i RAN and vocabulary. The articular deficits f ALLS in PA are further supported by studies comparing native and non-native speaking ALLS: Native speaking ALLS performed w rse or at best as well as non-native ALLS i PA. In contrast, hey performed better i v cabulary and language rocessing and a least equally well i RAN. This suggests ha he reading difficulties f native speaking ALLS may be caused by an underlying deficit in PA, while non-native speaking ALLS have rather a m re eneral second language roblem.

The fact hat ALLS have worse PA han reading-level matched children shows how large the deficits are i his cognitive function. In contrast, he consistently better erformance f ALLS in RAN may be explained by he faster eneral rocessing speed of adults (e.g., Luna e al., 2004; maturation hypothesis, Grosche, 2012), which could mask a ossible deficit i ALLS in his phonological componen . Moreover, i is surprising hat ALLS were better i v cabulary han children, iven he association between vocabulary and age, i. e., increases in language experience with age (e.g., Pfost e al., 2014).

Comparing the ALLS' profile at information rocessing level with hat f DD, the f llowing differences emerge: individuals with DD are usually impaired in all cognitive functions studied, i cluding in hose in which ALLS do show any deficits, such as in rtho-graphic knowledge. Thus, i meta-analyses children and adults with DD erform worse han heir peers without the diagnosis i (1) honological rocessing abilities, i.e., PA, RAN, WM and (2) in her ha c itive honological recursor functions, such as orthographic knowledge, and also, even though with lower effect sizes, i perception, vocabulary, oral language c mprehension and intelligence (Araújo & Faísca, 2019; Carioti e al., 2021; Georgiou et al., 2021, 2022; Kudo et al., 2015; McWeeny e al., 2022; Melby-Lervåg et al., 2012; Noordenbos & Serniclaes, 2015; Parrila et al., 2020; Reis et al., 2020).

Effect sizes were larger when individuals with DD were compared with age-matched controls han with reading-level matched controls (Georgiou et al., 2021, 2022, Melby-Lervåg et al., 2012; f r effects in RAN c mpared reading-level matched controls, see Araújo & Faísca, 2019). A major difference between the results of ALLS and DD is hat large deficits i rthographic knowledge are found i he latter, while his was the case for ALLS. I fact, as discussed earlier, he resent results suggest hat ALLS rely more orthographic strategies and less honological strategies, likely due their deficits i PA.

In contrast adults with DD, whose intellectual ability is within he normal range by definition (Mather & Schneider, 2023), he majority f the reviewed studies show hat ALLS performed slightly r significantly below he ulation 's average intelligence level. The complex interplay between formal education (particularly relevant for ALLS), literacy, and eneral intelligence u derscores he need for caution when attributing poor reading skills low intelligence, as his can lead invalid conclusions about heir relationship (Bulajić e al., 2019). Firstly, several researchers inted ut he weak c rrelation between intelligence and decoding skills in adults, while education attainment is more strongly correlated with intelligence (see Gustafson & Samuelsson, 1999). Secondly, oor reading skills can negatively impact erformance i elligence ests (Gustafson & Samuelsson, 1999). Some well-controlled win studies suggest hat reading ability i creases performance even i fluid i ellig ence and non-verbal intelligence ests (Ritchie, Bates, & Plomin, 2015). Thereby, hirdly, the impact of education fluid intelligence, as assessed i abstract reasoning tests, must be considered in particular. For example, Luria (1976) influential finding hat, compared more-educated Muscovites, less-educated Siberian villagers had more difficulties in abstract, hypothetical, and counter-intuitive reasoning, can be explained by he impact of formal education which intensely fosters abstract reasoning (Flynn, 2009). In fact, ALLS, mostly with lower education, seem deal with abstract tasks i a different way. Thus, Bulajić e al (2019) analyzed the abstractness level f the responses obtained from ALLS and u iversity students he WAIS-R V cabulary subtest and c cluded hat he differences between he roups riginate more from heir intellectual *habitus*, han from a intellectual capacity. Fourthly, standard intelligence ests er se may be inadequate for low-literate ulations, ften yielding unrealistically low results due their unfamiliarity wi h ests, est situations, a d other confounding factors (Ardila & Rosselli, 2007). Thus, some studies have found hat ALLS scored surprisingly low non-verbal i elligence ests, despite demonstrating average conversational abilities in interviews r est repara ion (Vágvölgyi e al., 2019).

In conclusion, ALLS's oor reading skills and reading-related cognitive functions cannot be explained by heir erformance standard intelligence ests. Ecologically valid assessments adapted f r he low-literate ulation are eeded fairly and more validly evaluate the i elligence f low-literate ulations.

4.3. Neurobiological level

In erms f he eurobiological level, research is scarce and hose hat have examined neural correlates suggest hat most differences might be more about c sequences f han causally related low reading skills. Indeed, both ALLS and LA showed a c mparable left N170 rint uning component, which was more negative for letter han symbol strings (Boltzmann & Rüsseler, 2013). In contrast, both children and adults with DD usually show a reduced N170 relative control readers (e.g., Araújo e al., 2012; Araújo et al., 2015; Mahé e al., 2012; Amora e al., 2022, but see also Maurer et al., 2011, for comparable N170 for dyslexic and age-controls at the a e f 11). This indicates a impaired coarse eural uning f r rocessing letter strings in both groups (but see Mahé e al., 2013). This finding suggests hat impaired N170 rint uning c mponent is a hallmark f DD, but of low literacy per se. However, i is important e hat rint uning is crucially dependent reading experience (Maurer et al., 2011), and may be lower in individuals with DD and ALLS compared LA, exactly because f heir respective lack of reading experience. I addition, it is likely hat rint uning (like reading performance itself a d the associated structural and functional changes in the brain) depends ly the quantity but also he quality f he reading experience. I c mparison typical readers, the quality f he reading experience is likely differ for ALLS as well as for individuals with DD (Huettig, Lachmann et al., 2018).

Boltzmann e al. (2017) have identified structural and functional differences between ALLS and LA (in re-literacy raining of ALLS condition). These atterns are similar hose when comparing individuals with and without DD. Reading i volves the c eration f three distinct and distributed brain systems (predominantly left-lateralized reading etwork) from which (1) he emporo-parietal system is involved in honological rocessing and decoding; (2) he ccipito-temporal system (including he visual word form area) is s ecialized in visual word recognition and rthographic processing; and (3) he i ferior-frontal system is responsible f r cognitive control and attention (for review, see Vandermosten et al., 2012).

Structural differences between ALLS and LA found in MRI were mostly found i brain regions underpinning honological rocessing (Boltzmann e al., 2017). Prior literacy raining of ALLS, structural differences found in he temporo-parietal region between ALLS and LA reflect heir difficulties in honological processing. This is c ruent with he findings reported in the results section, showing ALLS predominantly adopt a rthographic reading strategy, and hence, rely less he dorsal emporoparietal honological route, but more the ventral occipitotemporal lexical (orthographic) route (see, e.g., he proposed reading paths i he brain; Church et al., 2021). Indeed, his suggestion coheres with he results by Boltzmann e al. (2017) of differences between ALLS and LA exclusively in he emporo-parietal pathway a d their reduction after a i en sive literacy raining.

In comparison ALLS, individuals with DD show differences i additional brain regions relative heir peers, including reduced gray matter volume and different fMRI activations, only in temporo-parietal regions, but also in occipito-temporal and in frontal regions (for meta-analyses, see Eckert e al., 2016; Linkersdörfer et al., 2012; but see Ramus e al., 2018).

Similarly, the reduced functional connectivity during reading (Boltzmann e al., 2017) and during rest (Mohammadi et al., 2020) found i ALLS compared LA is smaller han he e previously reported i DD. Functional connectivity in ALLS was reduced i ly some, but all, brain s ructures hat show reduced FA i readers with DD (see Boltzmann e al., 2017). In the latter roup, reduced functional white matter connectivity was found during reading and rest in the e ire typical left hemisphere reading network (for a review, see Vandermosten et al., 2012, but see also Ramus e al., 2018). Interestingly, functional connectivity in ALLS was aligned with the c ectivity f the LA after training. This is be expected, as in typical readers studies have found a relationship between an increase in white matter connectivity and a increase i reading skills during literacy acquisition (for a verview see, e.g., González et al., 2022). However, i DD intervention-induced changes i he regions f he typical reading etworks (and i ther regions) were found as well (for a recent review, see Braid & Richlan, 2022). Furthermore, changes i structural white matter connectivity a d integrity could be associated with improvements i reading skills in his group. The findings regarding intervention-related brain changes are, however, quite mixed. A recent meta-analysis by Perdue et al. (2022) for instance, revealed i ervention-related changes i brain activation, although it should be ed hat his work included ly few studies hat met i s methodological requirements for inclusion.

5. Conclusions, limitations, and future directions

With his systematic review, we aimed summarize, categorize and synthesize current knowledge ALLS rounded he *Multi-level framework of Developmental Dyslexia* (Lachmann & Bergström, 2023) discuss ossible links DD. The main s rength f ur review is its reliance he explicit definition of ALLS with hree specific criteria (i.e., reading level, age, and education level), while considering both behavioral and eurobiological findings.

Not surprisingly, ur results confirm and validate hat ALLS performed worse han LA only in various reading and spelling asks at skill level but also i tasks assessing cognitive functions at information rocessing level. Moreover, ALLS exhibit structural a d functional differences i c mparison LA a he neurobiological level. The level specific difficulties and differences f ALLS, identified in our systematic review, are, some extent, similar hose previously identified i recent meta-analyses and reviews DD, albeit being more extensive i he latter roup. This, however, cannot be interpreted in erms of shared causes f r the low literacy skills in both roups. N e hat, based results reviewed here, the difficulties observed at information rocessing level, as well as he differences a he neurobiological level, in ALLS as well as i DD, could be the cause for low literacy skills, heir consequence, or both, combining and/or i fluencing each other reciprocally in different ropor tions across he wo roups.

For distinguishing between cause and consequence f low literacy skills, the use of a reading-level matched design in combination with a age-matched design, as ften applied in dyslexia research (e.g., Bryant & Goswami, 1986; Goswami, 2015), seems romising (Grosche, 2012). According he logic f his ype f matched design, the f llowing inferences can be drawn: if ALLS would show lower erformance han reading-level matched children, hen it could be i ferred hat a deficit is causally related with ALLS r reading skills. However, when he wo groups would show equal performance, for instance due he use f otential compensatory strategies (e.g., orthographic knowledge), hen null differences are susceptible ambiguity, and hence, he reverse inference cannot be made (see Bryant & Goswami, 1986; Goswami, 2015; Vellutino & Scanlon, 1989). However, reading-level matched designs have been criticized due heoretical and metric shortcomings (e.g., confound with age; difference in metric characteristics f reading measures, assumption f homogeneous development of different reading measures) with he conclusion hat hey can lead biased inferences (e.g., Van den Broeck & Geudens, 2012; Zoccolotti, 2020). To vercome the shortcomings f this method, a least regarding questions at skill level, alternative methods c rolling for c foundi variables, such as state trace analysis (Van den Broeck & Geudens, 2012) a d the rate and amount model (Zoccolotti, 2020), were proposed. In contrast reading-level matched design studies in dyslexia research, studies using hese alternative methods failed show eneralized selective pseudoword decoding deficits. While some studies in the eligible apers i he current review have used reading-level matched designs, study was f und hat used he mentioned alternative methods. An investigation of research questions a skill level in future studies using hese alternative methods would herefore be a romising extension. However, which extend the methods may be adapted investigate causal influences f cognitive functions reading remains be shown i future s udies. Ultimately, longitudinal studies r intervention studies (including matched control roups) are eeded reliably conclude a causal relationship between impaired cognitive functions and reading erformance (Goswami, 2015).

However, we would also like emphasize hat he results relate ly our specific arget roup and are ecessarily ransferable other individuals who typically also participate in adult foundational education. The samples of all included studies fulfill entirely the criteria for defining ur arget roup. N e hat if he criteria for roup definition were different (e.g., higher reading level), this might result i a different c itive rofile.

Moreover, we cannot exclude he ssibility hat artially verlapping samples were used f r the analyses i he included studies, as several articles were ublished by the same research eams. This would lead a ver-representation f the findings obtained with these samples in our review. It is nevertheless important report hese i he systematic review, as results f different ests and therefore different analyses were reported i he individual ublicatio s.

In the current systematic review, we considered only studies hat report some basic characteristics in the ALLS sample (i.e., reading level, age, education level) hat meet ur predefined criteria. Thus, several romising studies had be excluded because hey did describe this basic i formation f their sample(s) roperly. *Adults with low literacy skills* and synonymous terms such as *struggling adult readers*, *adult l teracy students* r *poor reading adults* are broad terms and might mean different reading levels in different research groups. I hese s udies, he corresponding level might refer a whole spectrum of low literacy, starting from the level hat could be observed in adults who cannot read and write at all and ending at the level seen in university students who erform rer han heir average erforming peers d .

Furthermore, despite hat a ssible verlap between DD and ALLS is discussed for decades (for review see, e.g., Vágvölgyi e al., 2016), most f the included studies did consider he revalence of DD r other learning disabilities among ALLS' sample characteristics. Two studies in our review explicitly excluded individuals with learning disabilities (including DD), seven included hem, while 18 studies did provide any i formation about his issue. ALLS are clearly a clinical ulation but i is s ill ecessary describe hem, only qualitatively, but also quantitatively increase the c mparability f different studies across countries, cultures, and research fields. Thus, for future studies, we recommend describing: (1) reading level (expressed i GE score or T-score), (2) level f education (e.g., years f schooling), (3) native language(s) and language(s) of instruction, (4) selection criteria/definition, (5) information previously diagnosed learning disabilities as well as (6) demographic background and SES including he educational level f he primary family. Future s udies hat include his information could help clarify the relevance of DD in ALLS.

The results f he resent systematic review could have ranslational outcomes i adult literacy learning and i struction, entially affecting policy makers and learning providers, as well as instructional designers, andragogists, and eachers. Our findings suggest hat it is crucial btain i sights only in the reading skills f the ALLS during the literacy learning process, but also i heir reading-related cognitive functions, before an intervention process even begins. Additionally, we recommend a f llow-up assessment for a more advanced u derstanding f he changes i he articipants ' cognitive rofiles during a d after he intervention. With his approach teachers may assign the learners ptimally suited groups with customized instructional units according heir individual cognitive rofiles a d eeds. We suggest applying formative rather han summative assessment c inuously monitor skill improvement, as well as imization of functions information processing level, allowing for customized i struction for ALLS (for a systematic review effective assessment principles see Bin Mubayrik, 2020).

As ALLS were shown have problems i both reading comprehension and decoding skills, literacy programs should be based rather a honetic approach (Solórzano, 1993). However, instructional designs of contemporary adult literacy programs are usually strongly influenced by ragmatism, rinciples f self-directedness a d rior experiences, critical pedagogy, a d (post)Vygotskian socio-constructivism (see Taylor et al., 2003). These a roaches emphasize c llaborative learning, using real-life materials (Purcell-Gates e al., 2002), and critical examination of social practices (Lavander & Tuckett, 2020; Kazemek, 1985). Furthermore, these approaches distanced literacy education from more skill-oriented methods focused, for instance, comprehension. Approaches focused comprehension at the expense of decoding could be described in erms f he *Simple View of Reading* as an attempt develop a higher order literacy skill (reading comprehension) without su rting foundational lower level skills (such as decoding; see Gough and Tunmer, 1986). In addition, contemporary programs rely problem-based and s cio-co structivist learning approaches and minimize he eacher's uidance and explicit instruction, an approach criticized by roponent s f cognitive load heory as being unsuitable for skill learning due unnecessary extraneous WM load (Sweller e al., 2007). The results f ur review strongly recommend at least supplementing the current instructional practices i adult basic education with directive honics raining (phonics approach).

Given he learning behaviors i day 's media world, ext comprehension combined with ictorial information is becoming increasingly important, leading different i formation rocessing compared reading ext in isolation. Based cognitive media theories, e.g., the c itive heory of multimedia learning (Mayer, 2020, for an overview see Mayer, 2024) r he integrated model f ext and icture c mprehension (Schnotz, 2014), future research could investigate what extent and under which conditions visual information in multimedia learning improve ext comprehension in ALLS. More specifically, i could be examined whether visual aids can be used actively compensate for lower reading skills or, conversely, if hey might introduce additional extraneous cognitive load (Sweller e al., 2007) hat hinders ext comprehension. This is particularly relevant iven the lower WM erformance bserved i ALLS. Findings from this future research may provide further guidance for ractice.

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Declaration of ompeting nterest

The authors declare the f llowing financial interests/personal relationships which may be considered as potential c mpeting interests: Thomas Lachmann reports financial support was provided by Federal Ministry f Education and Research. If there are her authors, they declare hat hey have known c mpeting financial interests r ersonal relationships hat could have appeared influence the work reported i his aper.

Acknowledgements

This work was supported by a rant from he German Federal Ministry of Educa ion and Research (BMBF 01GJ1801) awarded Thomas Lachmann, Maria latte and Kirstin Bergström (RPTU Kaiserslautern-Landau). Thanks are due he following members f he scientific advisory board f his roject for heir valuable contributions: Régine olinsky (Université Libre de Bruxelles, Belgium), Mary-Helen Kosmidis (Aristotle University f Thessaloniki, Greece), Claudia Mähler (University f Hildesheim, Germany), and Sven Nickel (Free University f Bozen-Bolzano, Italy).

Appendix A. Supplementary data

Supplementary data this article can be found online at https://doi.org/10.1016/j.edurev.2024.100659.

Data availability

Data will be made available request.

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