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Is Developmental Language Disorder Associated with Slower Processing Speed Across Domains?

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Background

- Processing speed, often measured via reaction/response time (RT) paradigms, has been linked to various linguistic abilities, such as articulation, lexical access, vocabulary knowledge, and reading comprehension,[1,2,3,4] and other mental operations, such as working memory and attention.[3]
- Individuals with *Developmental Language Disorder* (DLD) have been found to respond more slowly than neurotypical age-matched individuals across a variety of tasks. The generalized slowing hypothesis[5] proposed that deficits in processing speed observed in DLD may be domain general as opposed to restricted to linguistic processing.
- Understanding whether and to what extent generalized slowing characterizes individuals with DLD has implications for clinical diagnosis, intervention, and practice.[6,7]
- Most of this research on generalized slowing was conducted over a decade ago, and RT measures from DLD studies have never been adequately synthesized.
- A previous meta-analysis attempted to synthesize the RT literature in DLD.[8] However, this meta-analysis drew from a non-systematically collected set of studies and was done prior to current advances in statistical methods, i.e., robust variance estimation (RVE) meta-analysis. Therefore, the sample may have been biased and the analysis lacking in methodological rigor.
- In the present systematic review and meta-analysis, we sought to address the need for a current and rigorously conducted synthesis of research examining the association between DLD diagnosis and processing speed.

Systematic Review

Search: We searched ProQuest using Boolean combinations of terms: *language impairment, Developmental Language Disorder, Specific Language Impairment, DLD, SLI, reaction time, RT, response time, naming, interference control*. We utilized listserv announcements to obtain unpublished data. We conducted forward searches and used reference lists of review articles.[5,8,9,10,11] When data were not readily available, authors were contacted.

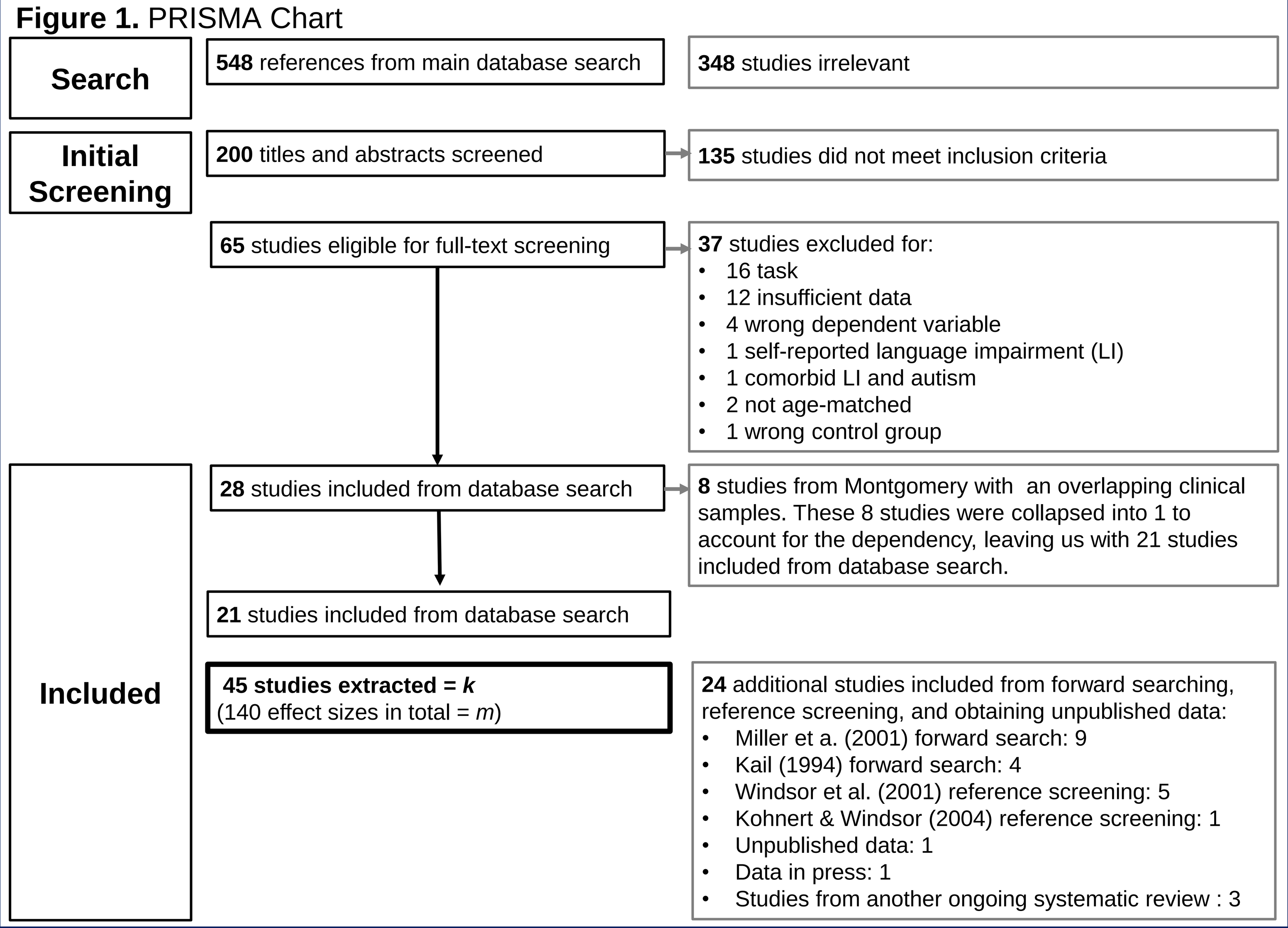
Inclusion Criteria: Figure 1 shows the PRISMA flow diagram depicting the study selection criteria. Studies had to include:

1) a DLD group (also called *Specific Language Impairment, non-specific language impairment, language disorder, primary language impairment,* and *receptive and/or expressive language impairment)* and an age-matched neurotypical groups
2) a RT measure, which required individuals to process stimuli and make a timed response
3) be written in English.
4) Studies were not restricted based upon the mean age of the DLD sample.

Data extraction: Two coders independently extracted effect size estimates for 43% (k = 18) of the included studies (inter-rater reliability = 92% agreement). Inconsistencies were resolved by the two raters reviewing the data and reaching consensus.

Final meta-analytic sample: The final sample consisted of 45 studies (*k*) with 140 effects (*m*). Age of DLD group: *mean* = 8.9 years; *median* = 8.6, *range* = 4.3 to 22.7

Figure 1. PRISMA Chart



Method

Tasks

The meta-analysis used processing speed estimates taken from four types of tasks, which were selected to minimize complexity and provide relatively simple measures of processing speed.

Task	Operational Definitions and Examples
Simple RT *k* = 23, *m* = 53	Instructions stated that when the participant saw or heard a stimulus, they must make a specified response. • Task did not require the participant to make a choice between stimuli, match, or categorize them. • Required minimal cognitive processing as there was no distractor stimulus and no conflict between the stimulus and response. • In one study[12], we extracted an estimate of processing speed from Epoch1 of an alternating serial RT task prior to extensive sequence learning.
Choice RT *k* = 11, *m* = 18	Instructions asked participants to distinguish between two or more simple stimuli. • Lexical decision tasks[13] were included as instances of the choice RT task. Here we included RTs from "word" only, excluding RTs for "nonword" conditions. • In one study[7], participants looked at a red or blue circle. They were instructed to press the red key if the circle was red, or the blue key if it was blue.
Naming *k* = 12, *m* = 25	Instructions asked participants to name visual stimuli (e.g., pictures) out loud as quickly and accurately as possible. • In one study[14] providing an example of a typical naming task, children were shown 64 pictures and instructed to name the depicted objects as quickly as possible.
Interference control *k* = 15, *m* = 44	Instructions asked participants to respond to a target stimulus while ignoring a distractor or withhold a response to a non-target stimulus and only responding to targets. • Only congruent, neutral, or baseline conditions were chosen to minimize interference/conflict. Neutral and baseline conditions were preferred over congruent conditions when available. • The tasks included variations of Flanker, Go/No-Go, Stroop, picture-word interference, picture-picture interference, and cross-modal recognition tasks. • In one study employing the Stroop task,[15] we extracted RTs from a neutral condition requiring participants to respond to a string of the letter "x" as the target.

Moderators

Moderator	Coding	Number of Studies
Stimulus Type	**Linguistic:** Single digits, single letters, digit/letter strings, words, and pseudowords used as primes and/or targets, presented either auditorily or visually **Nonlinguistic**: Shapes, figures, colors, or objects	**Linguistic:** *k* = 16, *m* = 46 **Nonlinguistic:** *k* = 35, *m* = 94
Stimulus Modality	**Auditory:** Task included one or more stimuli (e.g., prime, distractor, or target) presented in the auditory modality **Nonauditory:** Task did not have any auditory component	**Auditory:** *k* = 28, *m* = 82 **Nonauditory:** *k* = 24, *m* = 58
Response Modality	**Verbal:** Task required a vocal response to a stimulus, e.g., saying "yes" or "no" or naming the stimulus **Nonverbal:** Task required the movement of a body part to elicit a nonverbal response, such as a button press	**Verbal:** *k* = 19, *m* = 70 **Nonverbal:** *k* = 30, *m* = 70

Results

Figure 2 Funnel Plot of Effect Size Estimates for Linguistic and Nonlinguistic Stimulus Types

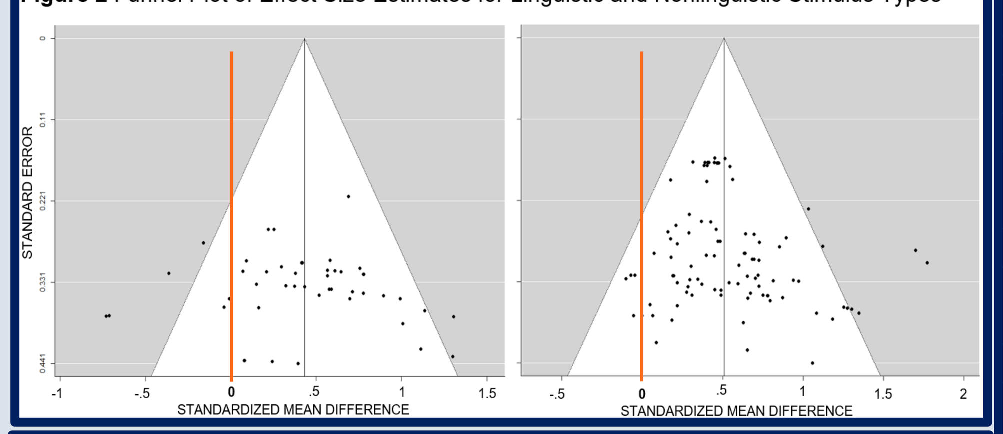


Figure 3 Funnel Plot of Effect Size Estimates for Auditory and Nonauditory Stimulus Modalities

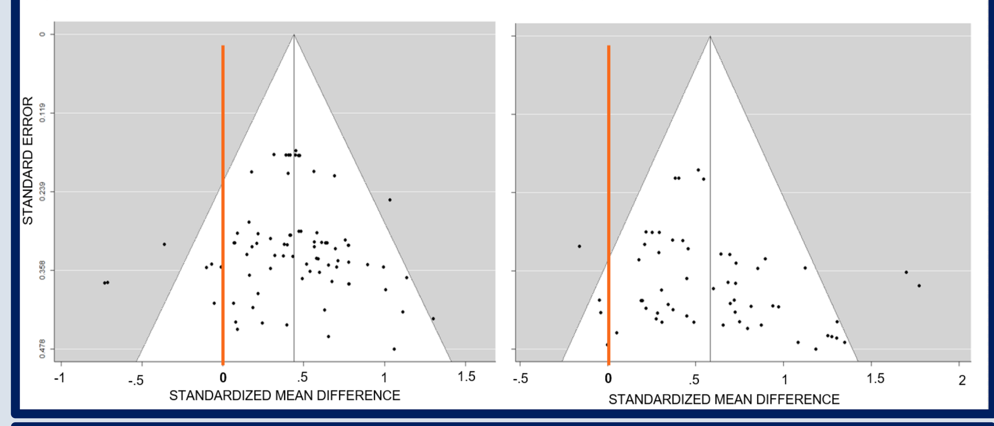


Figure 4 Funnel Plot of Effect Size Estimates for Verbal and Nonverbal Response Modalities

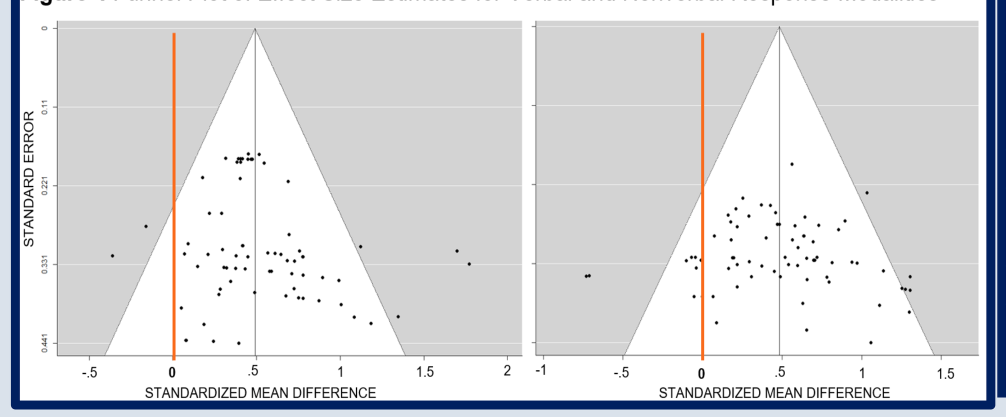


Table 1. Summary of variables in meta-regression models.

Variables	Meta-Regression Summaries			
	Estimate	*SE*	*95 % CI*	*p*
Model 1				
Intercept	.43	.04	.34; .52	
Age	–.02	.01	–.06; .01	.15
Model 2				
Intercept	.49	.05	.40; .59	
Stimulus Type (Linguistic)	–.11	.11	–.35; .12	.33
Model 3				
Intercept	.56	.06	.43; .68	
Stimulus Modality (Auditory)	–.17	.08	–.34; –.01	.04
Model 4				
Intercept	.41	.06	.29; .53	
Response Modality (Verbal)	.14	.09	–.04; .32	.12

Table 2 Sub-group analysis of moderator categories.

Moderator	Sub-group Analysis Summaries			
	Effect Size (g)	*SE*	*95 % CI*	*p*
Task Type				
Simple RT	.44	.07	.30; .58	< .001
Choice RT	.55	.08	.37; .74	< .001
Naming	.70	.14	.40; 1.01	< .001
Interference Control	.39	.05	.27; .50	< .001
Stimulus Type				
Linguistic	.44	.10	.23; .64	< .001
Nonlinguistic	.50	.05	.40; .60	< .001
Stimulus Modality				
Auditory	.39	.05	.28; .50	< .001
Nonauditory	.55	.06	.43; .67	< .001
Response Modality				
Verbal	.58	.08	.42; .75	< .001
Nonverbal	.41	.06	.30; .53	< .001

- Effect size estimates (*g*) were calculated using random-effects robust variance estimation utilizing *Metafor*[16] and *Robumeta*[17] packages in R.
- The overall effect (intercept-only model) indicated significant slower processing speed (longer RTs) in DLD groups as compared to age-matched neurotypical groups (small-to-medium effect: g = .47, p < .001, 95% CI = .38; .56). Mean age of the DLD group, grand-mean centered and entered as a co-variate, did not moderate estimates (see Table 1).
- Subgroup analyses for each moderator were run using RVE (intercept-only model for each moderator category). The subgroup analyses demonstrated significance across all stimulus types, stimulus modalities, and response modalities, in support of generalized slowing (see Table 2).
- The distribution of effects in each stimulus type (linguistic/nonlinguistic), stimulus modality (auditory/nonauditory) and response modality (nonverbal/verbal) domain are displayed in Figures 2–4. A value with standardized mean difference = 0 (noted by an orange vertical line) indicates no difference in RT between groups. Notably most effects indicated slower RTs in the DLD group.
- Meta-regression analysis examined whether DLD groups were slower for verbal vs. nonverbal stimulus types, auditory vs. nonauditory stimulus modalities, and verbal vs. nonverbal response modalities. As shown in Table 1, the only moderator to reach significance was stimulus modality (p = .043). Counter to predictions associated with auditory processing theories of DLD,[18] coefficients indicated larger effect size estimates (i.e., greater slowing) for tasks with nonauditory as opposed to auditory stimuli. However, slowing was evident in DLD for both auditory and nonauditory stimulus modalities (see Table 2).

Implications

The results suggest that processing speed may be a generalized deficit in DLD. Nonverbal RT assessments have the potential to assist in diagnosis of DLD in diverse participant groups.[6,7] Standardized clinical tests are available for only a small proportion of the world's languages and most have norms based on monolingual children. Such tests may be unreliable in detecting DLD in bilingual children and in speakers of nonstandard dialects. If nonverbal RT assessments are shown to have adequate sensitivity and specificity, they may help reduce bias in diagnosis and improve clinical methods for assessing language disorders. In clinical and educational contexts, interventions might aim to enhance information processing speed at a basic level rather than focusing solely on higher-order cognitive and linguistic abilities. Processing speed interventions (e.g., using action video games) have shown to be successful in increasing RTs of elderly and young adults[19,20] and may be adaptable for therapeutic use with children with DLD.

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