

1. Study characteristics and key findings

Table 2.
Systematic review study characteristics and key findings

Factor	Reference	Design	Participants	Age at language assessment in months	Language measure	Control variables	Language	Key findings
BIOLOGICAL FACTORS								
<i>Brain-based factors</i>								
Cortical reactivity	Kolesnik et al., 2019	Prospective	115 EL-sibs (64m, 52f) 27 TL-sibs (14m, 13f)	39.05	MSEL	EEG trial number	English	Cortical reactivity was associated with reduced receptive, but not expressive, language growth between 8 and 36 months, independent of group
Fractional anisotropy in the ILF	Naigles et al., 2017	Cross-sectional	104 ASD (104m)	38.80	M-CDI MSEL	Age Autism traits Handedness Nonverbal cognition Scanner status	English	Both receptive and expressive language was significantly correlated with fractional anisotropy in occipital portions the left and right inferior longitudinal fasciculus
Frontal delta power	Wilkinson et al., 2020 ²	Prospective	21 EL-sibs+ (14m, 7f) 51 EL-sibs- (25m, 26f) 58 TL-sibs (30m, 28f)	24.00	MSEL	Biological sex Parental education	English	For both EL-groups, 6 months intercepts of delta power were significantly associated with 24-month language
Frontal high-alpha power	Levin et al., 2017 ²	Prospective	25 EL-sibs (14m, 11f) 14 TL-sibs (9m, 5f)	36.00	MSEL	-	English	Frontal high alpha power was positively related to expressive language for children with and without ASD
Frontal theta power	Wilkinson et al., 2020 ²	Prospective	21 EL-sibs+ (14m, 7f) 51 EL-sibs- (25m, 26f) 58 TL-sibs (30m, 28f)	24.00	MSEL	Biological sex Parental education	English	For both EL-groups, 6 months intercepts of theta power were

								significantly associated with 24-month language
Gamma power	Romeo et al., 2021 ²	Prospective	10 EL-sibs+ (7m, 3f) 12 EL-sibs- (3m, 9f)	24.00	MSEL	-	English	The relationship between parent input at 18 months and expressive language at 24 months was mediated by frontal gamma power. For EL-sibs+ gamma power was negatively correlated with expressive language
	Wilkinson et al., 2019 ²	Prospective	15 EL-sibs+ (11m, 5f) 42 EL-sibs- (20m, 22f) 43 TL-sibs (13m, 11f)	36.00	MSEL	Biological sex Maternal education	English	For all EL-sibs only, increased frontal gamma was significantly associated with lower expressive, but not receptive, language. This effect was largely driven by females
	Wilkinson et al., 2020 ²	Prospective	21 EL-sibs+ (14m, 7f) 51 EL-sibs- (25m, 26f) 58 TL-sibs (30m, 28f)	24.00	MSEL	Biological sex Parental education	English	For both EL-groups, 6 months intercepts of gamma power were significantly associated with 24-month language. The impact of gamma power differed per EL-group: higher 6-month gamma power was associated with increased 24-month language in EL-sibs-, and decreased 24-month language in EL-sibs+
Left frontal-central alpha coherence	Tran et al., 2021	Prospective	36 EL-sibs (23m, 13f) 27 TL-sibs (17m, 10f)	18.00	M-CDI MSEL	-	English	For all participants, left frontal alpha coherence at 3 months was positively correlated with 18-month M-CDI words production
Neural correlates of face processing	Glauser et al., 2022 ²	Prospective	24 EL-sibs+ (15m, 9f) 41 EL-sibs- (19m, 22f) 45 TL-sibs (20m, 25 f)	12.00	MSEL M-CDI	Maternal education	English	A stronger P400 ERP for mother over stranger at 12 months was associated with better expressive and receptive language, also at 12 months, for EL-sibs+ only

[illegible]

Maternal education	Olson et al., 2021	Cross-sectional	62 ASD (46m, 16f) 45 TD (23m, 22f)	ASD 30.60 TD 28.90	MSEL VABS-II	Age Bilingualism Biological sex Ethnicity Intervention history	English	Maternal education was associated with both receptive and expressive language, independent of diagnostic status. Lower maternal education was associated with lower languages scores. This effect did not survive corrections for multiple comparisons
Mother rigidity (BAP traits)	Flippin et al., 2018 ³	Cross-sectional	16 ASD (12m, 4f)	53.30	MSEL PLS-4	Parental verbal responsiveness	English	A significant negative association was observed between mothers' rigidity and child language scores. For fathers', no association was between BAP traits and child language
Serum folate levels	Li et al., 2021	Cross-sectional	1300 ASD (1069m, 231f) 1246 TD (819m, 427f)	ASD 47.40 TD 53.04	ABC CARS CNBS-R2016	-	Mandarin Chinese	Serum folate levels were positively associated with language measured by the CNBS, but only in children aged three and younger
<i>Parental language input</i>								
Maternal gesture use	Talbott et al., 2013 ²	Prospective	48 EL-sibs (26m, 21f) 27 TL-sibs (14m, 13f)	18.00	MSEL	-	English	Maternal gesture use when the child was 12 months old, was significantly and positively correlated with language for EL and TL-sibs
Maternal MLU	Bang & Nadig, 2015	Prospective	19 ASD (14m, 5f) 44 TD (23m, 21f)	ASD 67.39 TD 37.40	M-CDI	Age Initial child language	English & French	Maternal linguistic input (MLU) positively predicted expressive vocabulary in both groups
	Choi et al., 2020 ²	Prospective	15 EL-sibs+ (10m, 5f) 25 EL-sibs- (9m, 16f) 27 TL-sibs (13m, 14f)	24.00	MSEL	Initial child language Parental education	English	Parent MLU at 18 months was significantly positively associated with child language abilities at 24 months

	Romeo et al., 2021 ²	Prospective	10 EL-sibs+ (7m, 3f) 12 EL-sibs- (3m, 9f)	24.00	MSEL	-	English	Parent input at 18 months significantly positively predicted receptive language at 24 months for all groups and expressive language for EL-sibs+ only. The association with expressive language was mediated by frontal and temporal gamma power
Parent verbal responsiveness	Grzadzinski et al., 2020	Prospective	83 EL-sibs (67m, 16f)	23.00	MSEL	Intervention history	English	Parent verbal responsiveness at 14 months significantly positively predicted language at 23 months
Paternal verbal responsiveness	Flippin et al., 2015 ³	Cross-sectional	16 ASD (12m, 4f)	53.30	MSEL PLS-4	Nonverbal cognition Household income Parental education	English	The frequency of verbal responsiveness of fathers, but not mothers, was positively associated with child language scores
Parent gesture quantity	Choi et al., 2021b ²	Prospective	17 EL-sibs+ (12m, 5f) 25 EL-sibs- (9m, 16f) 28 TL-sibs (14m, 14f)	24.00	M-CDI	Biological sex Initial child language Parent speech	English	For all groups, parent gesture quantity at 12 months positively predicted children's vocabulary at 36 months
Parent gesture type	Choi et al., 2021a ²	Prospective	17 EL-sibs+ (12m, 5f) 25 EL-sibs- (9m, 16f) 28 TL-sibs (14m, 14f)	24.00	M-CDI	Biological sex Initial child language Parent speech	English	12-month parental declarative gesture use was positively associated with children's 36-months vocabulary in all groups
Use of telegraphic speech	Venker et al., 2015	Prospective	55 ASD (51m, 4f)	54.20	Speech sample	Initial child language Nonverbal cognition	English	Telegraphic speech has a negative impact on language development in children with ASD
<i>Social factors</i>								
Frequency of other-directed vocalizations	Nevill et al., 2019	Cross-sectional	104 ASD (86m, 18f)	32.60	MSEL PLS-5 VABS-II	-	English	The frequency of vocalizations was significantly and positively related to expressive language

Increased attention to eyes and face	Righi et al., 2018	Cross-sectional	45 ASD (36m, 9f) 32 TD (21m, 11f)	ASD 61.44 TD 36.48	PLS-5	Age	English	Attention to the eyes in the videos was related to better language scores, independent of group
	Wagner et al., 2018 ²	Prospective	8 EL-sibs+ (3m, 5f) 29 EL-sibs- (18m, 11f) 40 TL-sibs (23m, 17f)	18.00	MSEL	Nonverbal cognition	English	For the two EL-groups there was a negative association between increased attention to the eyes and face (rather than to the mouth) at 6 months and expressive language at 18 months. This effect was not present for TL-sibs
Increased attention to mouth	Chawarska et al., 2022	Prospective	91 EL-sibs (56m, 35f) 61 TL-sibs (32m, 29f)	18.00	MSEL	Biological sex	English	Although there was a significant, positive effect of preferential attention to the mouth on the expressive language abilities of TL-sibs, no such effects were established for EL-sibs
	Habayeb et al., 2020	Cross-sectional	54 ASD (54 m) 28 TD (28m)	ASD 20.40 TD 19.09	MSEL	Age Nonverbal cognition	English	For children with ASD, looking at the mouth was significantly and positively associated with expressive language only, but only for children that acquired first words.
	Righi et al., 2018	Cross-sectional	45 ASD (36m, 9f) 32 TD (21m, 11f)	ASD 61.44 TD 36.48	PLS-5	Age	English	Attention to the mouth in the videos was related to better language scores, independent of group
Intentional communication	Su et al., 2021	Prospective	87 ASD (66m, 21f)	47.00	MSEL	Age Biological sex Initial child language	English	Early social motivation at 23 months predicted expressive language 2 years later. This effect was mediated by intentional communication and receptive language

Joint attention	Bruyneel et al., 2019b ¹	Prospective	31 EL-sibs (13m, 18f) 30 TL-sibs (17m, 13f)	EL 37.50 TL 38.81	MSEL	Nonverbal cognition	Dutch	The relationship between motor skills and receptive language was mediated by joint attention
	Edmunds et al., 2017	Prospective	50 EL-sibs (29m, 21f) 34 TL-sibs (16m, 18f)	EL 18.21 TL 18.22	M-CDI	-	English	The relationship between Mmotor imitation ability and expressive vocabulary growth was fully mediated by response to joint attention in EL-sibs and partially mediated for TL-sibs
	Frost et al., 2022	Prospective	65 ASD (45m, 20f)	44.85	VABS-II	Age Nonverbal cognition	English	Joint attention was positively related to both receptive and expressive language
	Nevill et al., 2019	Cross-sectional	104 ASD (86m, 18f)	32.60	MSEL PLS-5 VABS-II	-	English	Joint attention was significantly associated with receptive language
	Taylor et al., 2020	Prospective	249 ASD (197m, 52f)	70.8	EOWPVT-4 M-CDI VABS-II	Age Nonverbal cognition	English	Joint attention was significantly associated with receptive but not expressive language
Larger latency to respond	Northrup & Iverson, 2015	Prospective	25 EL-sibs (13m, 12f) 10 TL-sibs (5m, 5f)	EL 36.00 TL 19.00	CDI Group status (delay/no delay) MSEL	Maternal education Percentage simultaneous speech	English	Larger differences in the latency to respond between mother and child at 9 months negatively predicted language scores at 36 months
Object imitation	Frost et al., 2022	Prospective	65 ASD (45m, 20f)	44.85	VABS-II	Age Nonverbal cognition	English	Object imitation was significantly associated to expressive language, but the effect was rendered not significant if joint attention was included in the model
	Şengül et al., 2020	Cross-sectional	61 ASD (48m, 13f)	51.23	T-CDI	-	Turkish	Autistic children who had better object imitation, were more likely to have expressive language abilities

Object play	Şengül et al., 2020	Cross-sectional	61 ASD (48m, 13f)	51.23	T-CDI	-	Turkish	Autistic children who had better object play, were more likely to have expressive language abilities
Percentage simultaneous speech between parent and child	Northrup & Iverson, 2015	Prospective	25 EL-sibs (13m, 12f) 10 TL-sibs (5m, 5f)	EL 36.00 TL 19.00	CDI Group status (delay/no delay) MSEL	Maternal education Percentage simultaneous speech	English	Percentage simultaneous speech was a significant predictor of language delay
Preference for speech over non-speech	Yamashiro et al., 2020	Prospective	20 EL-sibs (16m, 11f) 20 TL-sibs (13m, 7f)	24.00	M-CDI	Nonverbal cognition	English	A preference for speech at 9 months was positively associated to children's expressive language at 24 months
Preference for synchronous over asynchronous videos	Righi et al., 2018	Cross-sectional	45 ASD (36m, 9f) 32 TD (21m, 11f)	ASD 61.44 TD 36.48	PLS-5	Age	English	Attention to synchronous videos over asynchronous videos was related with better language abilities.
Relative preference for faces over objects	Droucker et al., 2013	Prospective	14 EL-sibs (no info) 20 TL-sibs (no info)	18.00	M-CDI	-	English	A relative preference for faces over objects between 6 and 12 months was associated vocabulary at 18 months in EL-sibs
Social motivation	Su et al., 2021	Prospective	87 ASD (66m, 21f)	47.00	MSEL	Age Biological sex Initial child language	English	The relationship between social motivation and expressive language 2 years later was mediated by intentional communication
Social responsiveness	Taylor et al., 2020	Cross-sectional	249 ASD (197m, 52f)	70.8	EOWPVT-4 M-CDI VABS-II	Age Nonverbal cognition	English	Social responsiveness was significantly and positively associated with both receptive and expressive language
Symbolic comprehension	Taylor et al., 2020	Prospective	249 ASD (197m, 52f)	70.8	EOWPVT-4 M-CDI VABS-II	Age Nonverbal cognition	English	Symbolic comprehension was significantly positively associated with expressive but not receptive language

AGE-RELATED AND DEVELOPMENTAL FACTORS								
<i>Early language abilities</i>								
Early child vocalizations	McDaniel et al., 2020	Prospective	87 ASD (66m, 21f)	36.00	M-CDI MSEL Speech sample VABS-II	-	English	Early child vocalizations at 24 months significantly and positively predicted expressive language at 36 months
Initial child language abilities	Song & So, 2021	Prospective	42 ASD (36m, 6f)	57.42	Speech sample	-	Cantonese Chinese	Initial expressive child language skills were strongly and positively associated with expressive language nine months later
	Torras-Mañá et al., 2016	Prospective	135 ASD (121m, 14f)	48.00	Bayley-III ITPA MSCA K-ABC	-	Catalan & Spanish	Language abilities before the age of 3.5 years significantly predicted oral language levels at the age of 4 years.
<i>Cognitive factors</i>								
Nonverbal cognition	Bruyneel et al., 2019a ¹	Prospective	31 EL-sibs (13m, 18 f) 30 TL-sibs (17m, 13f)	EL 37.50 TL 38.81	MSEL	-	Dutch	For EL and TL-sibs, nonverbal abilities at 10 months positively predicted later receptive and expressive language
	Nevill et al., 2019	Cross-sectional	104 ASD (86m, 18f)	32.60	MSEL PLS-5 VABS-II	-	English	Nonverbal cognition positively predicted both receptive & expressive language
	Song & So, 2021	Prospective	42 ASD (36m, 6f)	57.42	Speech sample	-	Cantonese Chinese	No significant effects were observed
	Torras- Mañá et al., 2016	Prospective	135 ASD (121m, 14f)	48.00	Bayley-III ITPA MSCA K-ABC	-	Catalan & Spanish	Nonverbal cognitive abilities before the age of 3.5 years significantly predicted oral language levels at the age of 4 years.

<i>Gestures</i>								
Child gesture quantity	Choi et al., 2019 ²	Prospective	15 EL-sibs+ (10m, 5f) 25 EL-sibs- (9m, 16f) 29 TL-sibs (15m, 14f)	24.00	MSEL	Biological sex Nonverbal cognition Initial child language Parental education	English	Total number of child gestures at 12 months positively predicted receptive, but not expressive language at 24 months across groups
Child gesture type	Ökcün-Akçamış et al., 2019	Cross-sectional	72 ASD (62m, 10f)	62.76	Speech sample	-	Turkish	Child declarative and conventional/ pantomime gestures, but not imperative deictic gestures significantly predicted the number of different words used by participants
<i>Motor skills</i>								
Composite score motor skills	Bruyneel et al., 2019b ¹	Prospective	31 EL-sibs (13m, 18f) 30 TL-sibs (17m, 13f)	EL 37.50 TL 38.81	MSEL	Nonverbal cognition	Dutch	Lower motor skills were negatively associated with receptive language for both groups and with expressive language only for EL-sibs. This relationship was mediated by joint attention
	Wu et al., 2021	Cross-sectional	38 ASD (35m, 3f) 38 TD (35m, 3f)	ASD 33.02 33.24	MSEL	-	Mandarin Chinese	Motor functioning was significantly related to both receptive and expressive language. Higher motor scores resulted in increased language scores
Fine motor skills	Choi et al., 2018 ²	Prospective	22 EL-sibs+ (15m, 7f) 51 EL-sibs- (24m, 27f) 54 TL-sibs (30m, 24f)	36.00	MSEL	Biological sex Nonverbal cognition SES	English	Fine motor skills at 6 months positively predicted expressive language at 36 months. This effect did not differ per group

	Deserno et al., 2022	Prospective	73 EL-sibs+ (45m, 28f) 174 TL-sibs (73m, 101f)	36.00	MSEL	-	English	Although developmental trajectories of fine motor abilities and receptive and expressive language abilities were highly correlated, they were not coupled to each other in EL-sibs, regardless of later diagnostic status
	Patterson et al., 2022	Prospective	499 EL-sibs (279m, 220f) 176 TL-sibs (94m, 79f)	36.00	MSEL	-	English	Developmental trajectories of fine motor abilities were related to receptive and expressive language. Flatter developmental trajectories were related to lower language scores, and accelerating trajectories were associated with higher language scores
Gross motor skills	Patterson et al., 2022	Prospective	499 EL-sibs (279m, 220f) 176 TL-sibs (94m, 79f)	36.00	MSEL	-	English	Developmental trajectories of gross motor abilities were related to receptive and expressive language. Flatter developmental trajectories were related to lower language scores, and accelerating trajectories were associated with higher language scores
Motor imitation ability	Edmunds et al., 2017	Prospective	50 EL-sibs (29m, 21f) 34 TL-sibs (16m, 18f)	EL 18.21 TL 18.22	M-CDI	-	English	Motor imitation ability at 12 months positively predicted growth in expressive vocabulary regardless of risk status. This effect was fully mediated by response to joint attention in EL-sibs and partially mediated for TL-sibs
Postural control	Kyvelidou et al., 2021	Prospective	8 EL-sibs (5m, 3f) 11 TL-sibs (7m, 4f)	12.00	MSEL	-	English	Children with faster control over their postural control adaptations

								at 6 months had significantly higher receptive language abilities at 12 months. Low random movement (i.e., “steady sitters”) at 6 months was associated with better receptive and expressive language at 12 months
<i>Speech production</i>								
Speech production abilities	Saul & Norbury, 2020	Prospective	27 minimally verbal ASD (21m, 6f)	62.00	Oxford CDI	Autism traits Nonverbal cognition Receptive language	English	There was no significant relation between expressive language and communicative intent, parent responsiveness & response to JA. Speech production abilities (consonant inventory and phonetic repertoire) did significantly predict expressive language
<i>Word learning</i>								
Ability to map differentially stressed labels to objects	Ference & Curtin., 2015	Prospective	19 EL-sibs (11m, 8f) 19 TL sibs (11m, 8f)	EL 24.00 TL 12.00	M-CDI MSEL	-	English	The ability to map differentially stressed labels to objects at 12 months was predictive of expressive, but not receptive, language ability at 24 months in EL-sibs
Use of mutual exclusivity	Mathée-Scott et al., 2021	Cross-sectional	32 ASD (22m, 10f) 26 TD (16m, 10f)	ASD 30.69 TD 20.38	M-CDI PLS-5	Knowledge of nouns	English	For both autistic and neurotypical children, those who struggled with mutual exclusivity, had lower receptive language abilities

Note:

¹ These research articles both draw from the same study

² These research articles all draw from the same study

³ These research articles both draw from the same study

Abbreviations: ABC = Autism Behaviour Checklist; AMSE = Autism Mental Status Examination; BAP = Broader Autism Phenotype; CARS = Childhood Autism Rating Scale; CNBS-R2016 = Children Neuropsychological and Behavior Scale-Revision 2016; CSBS = Communication and Symbolic Behavior Scale; DD = developmental delay; EL-sibs = children with an elevated familial likelihood of ASD; EL-sibs+ = EL-sibs with eventual ASD diagnosis; EL-sibs- = EL-sibs without eventual ASD diagnosis; EL-sibs-LI = children with an elevated familial likelihood of language impairment; EOWPVT-4 = Expressive One-Word Picture Vocabulary Test; FA = fractional anisotropy; GDDS = Gesell Developmental Diagnosis Scale; ILF = Inferior Longitudinal Fasciculus; ITPA = Illinois Test of Psycholinguistic Abilities; K-ABC = Kaufman Assessment Battery for Children; LDS = Language Development Survey; M-CDI = MacArthur-Bates Communicative Development Inventories; MSCA = McCarthy Scales of Children's abilities; MSEL = Mullen Scales of Early Learning; MLU = mean length of utterance; Oxford CDI = UK adaptation of the M-CDI; PLS-4 = Preschool Language Scales-Fourth edition; PLS-5 = Preschool Language Scales-Fifth edition; PRES = Preschool Receptive-Expressive Language Scale; T-CDI = Turkish adaption of the M-CDI; REVT = Receptive and Expressive Vocabulary Test; SELSI = Sequences Language Scale for Infants; SES = socioeconomic status; TL-sibs = children with a typical likelihood of ASD; VABS II = Vineland Adaptive Behavior Scales, second edition

2. Assessment of Risk of Bias

Table 2.

Assessment of risk of bias

Study	Selection bias (Max. 4 stars, max. 2 if no control group present)	Comparability bias (Max. 2 stars, NA if no control group present)	Exposure bias (Max. 3 stars, NA if no control group present)	Overall Risk of Bias
Bang & Nadig (2015)	***	**	***	Low
Bruyneel et al. (2019 ^a)	**	*	**	Moderate
Bruyneel et al. (2019 ^b)	**	**	**	Moderate
Chawarska et al. (2022)	**	*	**	Moderate
Chen et al. (2021)	**	**	**	Moderate
Choi et al. (2018)	***	**	**	Low
Choi et al. (2019)	***	**	**	Low
Choi et al. (2020)	***	**	**	Low
Choi et al. (2021 ^a)	***	**	**	Low
Choi et al. (2021 ^b)	***	**	**	Low
Deserno et al. (2022)	**		**	Moderate
Droucker et al. (2013)	**	*	**	Moderate
Edmunds et al. (2017)	***	**	**	Low
Ference & Curtin (2015)	*	*	**	Moderate
Flippin & Watson (2015)	*			High
Flippin & Watson (2018)	*			High
Frost et al. (2022)	*			High
Glauser et al. (2022)	***	*	**	Low
Grzadzinski et al. (2021)	*			High
Habayeb et al. (2020)	***	**	**	Low
Kim et al. (2020)	*			High
Kolesnik et al. (2019)	**	*	**	Moderate
Kyvelidou et al. (2021)	**	*	**	Moderate
Levin et al. (2017)	***	*	**	Moderate
Li et al. (2021)	***		*	Moderate
Liu et al. (2020)	*	**	*	Moderate
Mathée-Scott et al. (2021)	***	*	*	Moderate
McDaniel et al. (2020)	*			High
Naigles et al. (2017)	*			High
Nevill et al. (2019)	*			High
Northrup et al. (2015)	**	*	**	Moderate

Øien et al. (2018)	*	*	***	Moderate
Ökcün-Akçamış et al. (2019)	*			High
Olson et al. (2021)	***	**	**	Low
Patterson et al. (2022)	**		**	Moderate
Pecukonis et al. (2021)	***	*	*	Moderate
Righi et al. (2018)	***	*	*	Moderate
Riva et al. (2018)		*	**	High
Romeo et al. (2021)	***	*	*	Moderate
Saul & Norbury (2020)	*			High
Sengül et al. (2021)	*			High
Song & So (2021)	*			High
Su et al. (2021)	*			High
Talbott et al. (2013)	***	*	***	Low
Taylor et al. (2020)	*			High
Torras-Mañá et al. (2016)	*			High
Tran et al. (2021)	**	*	**	Moderate
Venker et al. (2015)	*			High
Wagner et al. (2018)	***	**	*	Moderate
Wallisch et al. (2021)	**	*	**	Moderate
Wilkinson et al. (2019)	***	**	*	Moderate
Wilkinson et al. (2020)	***	**	*	Moderate
Wu et al. (2021)	***	*	**	Moderate
Yamashiro et al. (2020)	**	**	*	Moderate
Star rating: 7-9 stars = low ROB; 4-7 stars = moderate ROB; < 4 stars = high ROB				