

The operationalization of coordinated attention and the relations to language development: A meta-analysis

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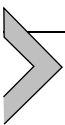
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Abstract

Using a structured literature search and meta-regression procedures, this chapter reports a study that sought to determine whether the associations between coordinated attention and language are moderated by operationalizations of coordinated attention, study design, and other participant characteristics. Studies were located using database searches. This resulted in 46 reports or datasets, 464 effect sizes representing 1,482 participants. Meta-regression was used to answer research questions regarding potential moderators of the effects sizes of interest, which were Pearson's r values quantifying the association between coordinated attention and

language assessments. In the final models, we observed that overall effect sizes were significantly above zero, suggesting robust effects across variables of interest. Age when coordinated attention was measured was a significant moderator, suggesting that the relations between coordinated attention and language was stronger when coordinated attention was measured at earlier ages. Interestingly, the longitudinal gap duration between coordinated attention measurement and language assessment was a significant moderator suggesting that the relation between coordinated attention and language was stronger when the longitudinal gap duration was longer. We conclude the meta-analysis by suggesting the phenomena of interest—dynamic coordinated visual attention between infant and caregiver—is robust across operationalizations and has predictive value for concurrent and future language abilities.



1. Introduction

In early development, the dynamic patterns of visual attention toward social partners and the environment are some of the important building blocks for language development. Mapping referents that are spoken by a caregiver to a particular object in a complex, cluttered visual environment is a difficult problem for the developing infant. Dynamically coordinating visual attention between a caregiver and an infant during object play can help reduce this referential ambiguity (Brooks & Meltzoff, 2005, 2008). Visual coordinated attention—how infants and parents distribute their visual attention towards objects and each other—has a long history in the study of language development. A large and growing literature on coordinated attention shows that the dynamic patterns of looking to one's social partner and towards objects in the environment are essential to language learning (Bakeman & Adamson, 1984; Brooks & Meltzoff, 2005, 2008; Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Morales, Mundy, & Rojas, 1998; Tomasello & Farrar, 1986; Tomasello & Todd, 1983).

Despite decades of empirical research showing evidence that patterns of coordinated attention are concurrently associated with language production and comprehension and also that these patterns are predictive months and years into the future, there is quite a lot of variability in how coordinated attention has been operationalized. For example, throughout the literature, there are major differences in the operationalization of coordinated attention such as around differences in gaze patterns, engagement levels, and who initiated the interaction. In this chapter, we report results from a meta-analysis to explore the role of variability in the operationalization of coordinated attention on the relation to language development.



2. Different accounts of coordinated attention

As noted in a recent paper (Gabouer & Bortfeld, 2021), how a researcher operationalizes coordinated attention during infant-caregiver interactive contexts can be influenced by factors such as their theoretical priors and traditions, their choices in terminology, and critically, how intentionality is attributed to both infants and their caregivers. In tackling the operationalization problem, Gabouer and Bortfeld highlighted two distinguishable accounts of coordinated attention, the ‘social’ account and the ‘associative’ account, while also describing their own new coding scheme for operationalizing coordinated attention. Note that Gabouer and Bortfeld focused on the term ‘joint attention’ but we use ‘coordinated attention’ in this book chapter because it encompasses more of the expansive literature about this phenomenon. Here, we will use their two accounts of coordinated attention to categorize past operationalizations in the meta-analysis.

The social account posits coordinated attention depends on triadic interactions between infants, caregivers, and objects in the environment that relies on contingent responses between infants and caregivers. Such contingent responses require social awareness from at least one social partner. Therefore, subjective assessments are used to assess social awareness and contingency. The primary divergence point between the ‘social’ account and the ‘associative’ account is that the social account requires assessments of social awareness, whereas the associative account does not. The associative account is a non-social perspective that is more dependent on the infants’ and caregivers’ visual orienting system. Given the primary goal of this meta-analysis is a systematic comparison of different operationalizations of coordinated attention and the relations with language development, we will use Gabouer and Bortfeld’s social/associative dichotomy to inform how we categorize effect sizes from empirical studies that investigated relations between coordinated attention and language development.

The “Early Social Communication Scales (ESCS)” is a widely used assessment of coordinated attention that includes a standardized process that affords many opportunities for coordinated attention episodes (Mundy, Fox, & Card, 2003). Crucially, in the ESCS, coordinated attention episodes are divided according to the social partner who initiated a coordinated attention bid. “Initiating joint attention” (IJA) occurs when the infant or child initiates a bid and “responding to joint attention” (RJA) occurs when experimenter (or caregiver) initiates a bid. The IJA/RJA

schema of the ESCS would be considered an example of the ‘social’ account given the use of intentionality in the coding of social awareness.

Operationalizations of coordinated attention that do not include an assessment of intentionality are considered within the associate account (Gabouer & Bortfeld, 2021). Indeed, Scaife and Bruner’s (1975) original operationalization would properly belong to the associative account given that there were no inclusion criteria of assessing social awareness or intentionality. A number of empirical papers on the relation between coordinated attention and language development focus objectively on how gaze patterns of infants and caregivers create bouts coordinated attention. One example is a recent paper that provided a mutually-exclusive set of gaze patterns between infants and caregivers (Abney, Suanda, Smith, & Yu, 2020). The gaze patterns included combinations of infant/caregiver gazes toward objects and the other social partner’s face and also basic rules for duration of a gaze. Abney et al. observed different associations between the proportions of the various coordinated attention bout types when infants were 9 months-of-age and their vocabulary sizes at 12- and 15-months-of-age. Specifically, the strongest positive associations were between vocabulary size and coordinated attention, and specifically when caregivers looked at both a mutual object and their infant’s face within short intervals while their infant was looking at the mutual object. Gaze patterns in Abney et al. were objectively recorded using dual head-mounted eye-trackers but many other empirical papers are categorized as associative accounts while using video recordings of gaze patterns that were subsequently hand coded.

Finally, Bakeman and Adamson (1984) introduced the terms “supported engagement” and “coordinated engagement” to operationalize different forms of so-called shared attention. Since then, many other researchers adopted their coding schemes. Bakeman and Adamson operationalized shared attention by taking into account the infant’s awareness of their caregiver’s attention and used a three-second coding rule to determine shared attention to an object or social partner. Further constructs were created such as ‘passive joint attention’ and ‘coordinated joint attention’, that are differentiated depending on the subjective assessment of whether or not the infant is showing an awareness of their caregiver’s presence. According to Gabouer and Bortfeld’s (2021) distinction about intentionality and social awareness, empirical papers using supported engagement or coordinated engagement operationalizations might be considered social accounts. However, given that gaze patterns from these particular operationalizations can be coded depending on gaze patterns, we will consider them as objective, associative-based operationalizations. Given

how coordinated attention has been historically operationalized and also given Gabouer and Bortfeld's (2021) useful distinctions between coordinated attention accounts, we will categorize effect sizes from empirical papers as either IJA, RJA, or gaze patterns.



3. Measures of child vocabulary

Empirical papers reporting concurrent or longitudinal associations between coordinated attention and language development have used a number of various assessments of infant vocabulary abilities. All papers included in this meta-analysis employed one of the following assessments of vocabulary development: communicative development inventory (CDI), Mullen Scales of Early Learning (MSEL), or Reynell Developmental Language Scale (RDLS). Each of these assessments provides a quantitative measure of productive (the words they produce on their own) and/or comprehension vocabulary (the words they understand when heard).



4. The present meta-analysis

The goal of the present meta-analysis is to systematically understand the relation between coordinated attention and language development through the lens of *operationalization variability*. Previous efforts have gone toward a systematic meta-analytic study of the relation between coordinated attention and language development focusing primarily on differences between typically development infants and infants diagnosed with autism spectrum disorder (Bottema-Beutel, 2016). The present meta-analysis differs in the following ways: (1) we restrict our analysis to studies of only typically developing infants, (2) include newly published studies (2016–2023), and (3) focuses on the difference between coordinated attention constructs that operationalize according to IJA, RJA, or gaze pattern schemas.

Studies included in this meta-analysis have varied operationalizations of coordinated attention, but all include similar experimental paradigms. For example, experimental sessions were often free-play paradigms or employed an ESCS setup. These interaction sessions that were used to measure coordinated attention were then followed by either concurrent or longitudinal assessments of vocabulary. The quantification of the strength of a

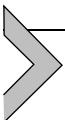
relation between coordinated attention and language ability is typically a correlation which is then converted to an effect size. Therefore, a large effect size is interpreted as a study having high amounts of coordinated attention and high scores on concurrent or longitudinal assessments of language skills (productive or comprehension).



5. Method

5.1 Search method

The search method for this meta-analysis involved querying the digital databases Google Scholar and PubMed. Both PubMed and Google Scholar were originally queried on 11/12/2021 and then queried again for additional research on 11/03/2023. The search string for PubMed on both queries was: (“joint attention” | “coordinated attention” | “mutual gaze”) AND (“word learning” | “language acquisition” | “language development” | vocabulary). 219 results were scraped by manual entry for inclusion from the PubMed queries. The search string for Google Scholar on both queries was: (“joint attention” | “coordinated attention” | “mutual gaze”) AND (“word learning” | “language acquisition” | “language development”) & cdi & (concurrent | longitudinal). 1416 articles were manually scraped for inclusion from the Google Scholar queries. A forward and backward literature search was conducted to check for the existence of empirical studies not captured by the digital queries.



6. Inclusion criteria

Selection criteria used to assess the eligibility of articles for inclusion in the meta-analysis were:

1. Includes a measure of comprehension or production of infant vocabulary
2. Includes a quantifiable measurement of level of engagement in coordinated attention behaviors
3. Report of a correlation (either longitudinal or concurrent) between coordinated attention and vocabulary variable. Correlation must be zero order, and either reported as a Pearson correlation or a metric that can be converted to a Pearson correlation
4. Operationalization of coordinated attention used to quantify these episodes must be defined in terms of explicit gaze patterns or IJA/RJA behavior measured using ESCS procedures



7. Exclusion criteria

Studies found in the digital queries were excluded from the meta-analysis if they:

1. Lacked typically developing participants in the experiment
2. Were not an experimental design (i.e., meta-analyses)
3. Re-reported data from past experiments already included in the quantitative analysis

Included below is a PRISMA flow diagram that documents the steps involved in the query process. PRISMA is an established standard for reporting meta-analyses with a focus on transparency and consistency in reporting results (Page et al., 2020). The flowchart demonstrates the process of each round of eliminations. The first round consisted of a general check of paper titles and abstracts to exclude work primarily based on the exclusion criteria. The second round consisted of a manual check of the remaining papers to ensure they meet all inclusion criteria. Also included in the flowchart is an enumerated list of second round reasons for exclusion. Finally, the flowchart indicates the total number of studies included in the quantitative meta-analysis.



8. Coding the studies

Features collected from the included studies were:

1. Sample size (N)
2. Age of child at time of coordinated attention measurement in months
3. Age of follow-up language assessment in months
4. Whether coordinated attention and vocabulary were measured concurrently or longitudinally
5. Operationalization of coordinated attention
6. Whether coordinated attention was operationalized as IJA, RJA, or GP
7. Whether the study employed ESCS in their coordinated attention operationalization
8. Language variable type (Comprehension/Production)
9. Measure of language assessment (CDI, RDLS, etc.)
10. Pearson r correlation value
11. Type of effect size that Pearson r was converted from, if applicable

Primary coding was conducted by a team of undergraduate and graduate students in the Developmental Dynamics Lab at the University of Georgia. After completing training, coders sorted the initial dataset as outlined in Fig. 1. The data used for analysis was coded by trained graduate students. All processing for this analysis was performed in R, using the *metaphor* and *meta* packages (Viechtbauer, 2010). Pearson's Product-Moment Correlation (r) was used as our effect size. To pool effect sizes between studies, correlations were converted to Fisher's z before pooling and converted back to Pearson's r for reporting (Borenstein, Hedges, Higgins, & Rothstein, 2009).



9. Results

Our literature search yielded a total of 464 effect sizes across 46 studies, representing 1482 participants. A summary of the characteristics of the studies included in our analyses is provided in Table 1. In this table, "Year" indicates the year of the study's publication, "N" indicates the sample size for which coordinated attention and vocabulary were

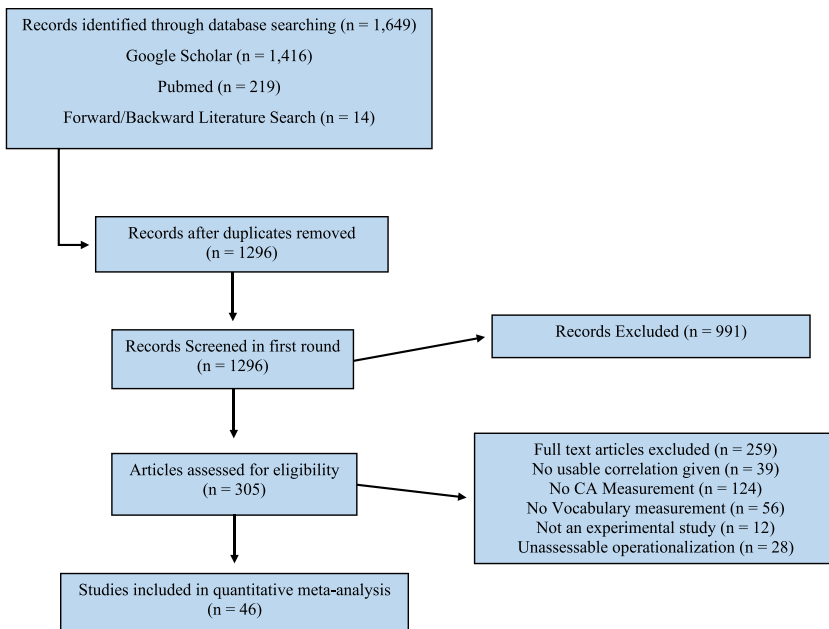


Fig. 1 PRISMA flow diagram summarizing search process.

Table 1 Characteristics of studies included in analysis.

Author	Year	Effect sizes	N	Age of CA	Conc/ Long	Comp/ Prod
Williams	2009	4	26	45	Conc	Comp
Vogrinčič	2020	6	30	13	Conc	Comp
Driggers-Jones	2019	8	88	15	Conc	Comp
Parikh	2017	2	30	9	Long	Comp
Sperotto	2016	8	58	13	Long	Comp
조윤정	2015	18	50	13	Long	Comp
Davidson	2016	8	100	9	Long	Prod
Mastin & Vogt	2016	36	14	13	Conc	Prod
Rollins	2003	2	11	12	Long	Comp
Henderson	2000	4	26	14	Long	Prod
Seager	2018	4	30	10	Conc	Both
Mundy et al.	2003	4	32	14	Long	Comp
Saxon	1997	8	24	6	Long	Prod
Eriksson	2019	4	14	12	Long	Comp
Saxon & Reilly	1998	1	60	25	Conc	Prod
Childers et al.	2007	4	8	14	Long	Comp
Tek	2010	5	18	21	Long	Prod
Heimann et al.	2006	4	23	14	Long	Comp
AbdelAziz	2017	6	33	20	Long	Comp
Okumura et al.	2017	4	37	9	Long	Prod
Carpenter et al.	1998	112	24	9	Long	Comp
Quinn	2016	8	52	18	Conc	Prod
Miller & Marcovitch	2015	8	47	14	Conc	Comp

(continued)

Table 1 Characteristics of studies included in analysis. (*cont'd*)

Author	Year	Effect sizes	N	Age of CA	Conc/ Long	Comp/ Prod
Namy & Nolan	2004	18	17	13	Long	Prod
Fletcher et al.	2005	2	21	21	Long	Both
Miller	2012	4	47	14	Long	Comp
Kushner	2019	2	14	18	Conc	Prod
Roemer	2018	2	14	12	Long	Both
Galeote et al.	2020	6	28	13	Conc	Comp
Charman et al.	2000	2	13	20	Conc	Prod
Ogura	2019	8	28	18	Conc	Prod
Ramirez	2017	2	8	23	Long	Prod
Mundy & Gomez	1998	10	24	17	Long	Prod
Morales et al.	1998	3	20	6	Long	Comp
Charman et al.	2000	8	13	20	Conc	Prod
Morales et al.	2000	32	22	6	Long	Prod
Markus et al.	2001	30	21	12	Conc	Comp
Slaughter et al.	2003	2	60	12	Conc	Comp
Abney et al.	2020	16	25	9	Long	Comp
Vuksanovic & Bjekic	2013	10	25	21	Conc	Prod
Van Hecke et al.	2007	4	52	12	Long	Comp
Salley et al.	2011	1	52	14	Long	Prod
Brooks & Meltzoff	2015	6	27	11	Long	Prod
Edmunds et al.	2017	6	34	12	Conc	Prod
Spicer-Cain et al.	2022	2	51	12	Conc	Comp
Ataman-Devrim et al.	2022	20	31	24	Long	Comp

measured, “Effect Sizes” indicates the number of effect sizes reported, “Con/Long” indicates if the study design was concurrent, longitudinal, or both, “Comp/Prod” indicates whether the study measured language production, comprehension, or both, “Group” indicates if the study operationalized coordinated attention using IJA, RJA, both RJA and IJA (IJA/RJA), or gaze pattern (GP), and “Age of CA” indicates the mean age (in months) that coordinated attention was measured in the children.

A summary of the distribution of effect sizes across the groups used for our comparative analyses is provided in Table 2. All groups were well represented, with each group exceeding the 10-study recommendation for generating summary effect sizes (Tanner-Smith & Tipton, 2014). However, it is worth noting that there were nearly double the number of RJA effect sizes (101) than there were IJA effect sizes (54), and more than triple the number of longitudinal effect sizes (346) than concurrent effect sizes (107). An ANOVA with effect size as a dependent variable and the type of language assessment as an independent variable suggested there were no significant differences across type of language assessment, $F(5, 458) = 1.83, p = 0.105$.

9.1 IJA vs. RJA

To compare the different measures of coordinated attention that were categorized as IJA, RJA, or GP and the relation to language development, effect sizes for all included studies were calculated and pooled in accordance to their group (Fig. 2). These results were then visualized using forest plots to compare summary effect sizes of our chosen groups along with the pooled effect for all studies across groups. Forest plots included in this study provide the effect size for each group. We also included a “weight” to indicate how much each group’s result contributes to the pooled total. Pooled estimates are represented graphically on a number line so that groups may be compared in parallel. Forest plots were created by pooling according to groups based on coordinated attention operationalization

Table 2 Distribution of effect sizes across groups.

Group	N	Concurrent	Long	Comp	Prod
IJA	54	12	42	21	32
RJA	101	25	76	34	66
Gaze	290	61	228	107	179

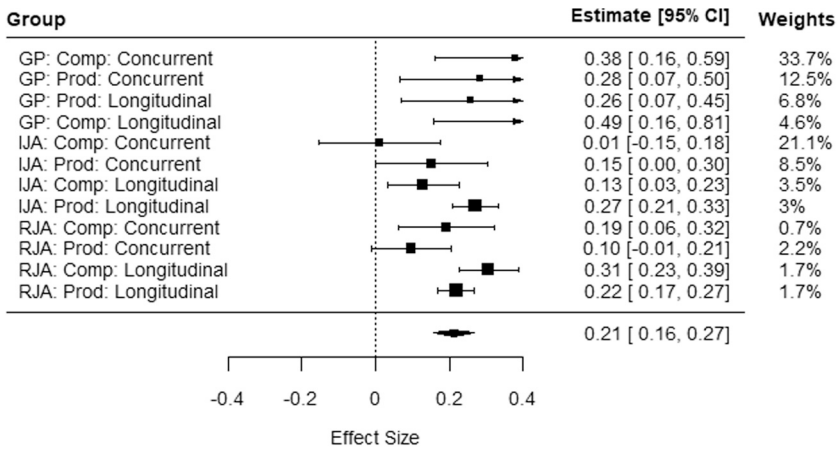


Fig. 2 Forest plot comparing pooled concurrent, longitudinal, production, and comprehension vocabulary effect sizes by operationalization groups.

(RJA, IJA, or GP), study design (concurrent or longitudinal), and to groups based on operationalization and language measure (comprehension or production).

Three random-effects meta-analyses were performed, each integrating 151 studies and applying the REML estimator, indicated a moderate degree of heterogeneity with tau-squared (τ^2) uniformly at 0.02. The I^2 index was 37.21%, signifying that over a third of the variability in effect estimates was attributable to heterogeneity. The H^2 metric was firmly at 1.59 for all analyses, underscoring that the variance observed was substantially more than what sampling error alone could explain. This was confirmed by a significant Q-test for heterogeneity (value of 244.36, $p < 0.0001$), authenticating notable heterogeneity across studies.

The concurrent and longitudinal effect sizes by ESCS group (Fig. 3) showed a significant pooled estimate of 0.22 with a 95% confidence interval spanning from 0.17 to 0.27. Another analysis, comparing pooled productive and comprehension vocabulary effect sizes by ESCS group, yielded a slightly higher pooled estimate of 0.24, with the confidence interval ranging from 0.17 to 0.30. The third analysis, which incorporated elements from both the preceding plots, presented a pooled estimate of 0.23, with confidence intervals of 0.19 to 0.27. These results show strong significant effects, as indicated by the non-overlapping confidence intervals, suggesting a robust and meaningful impact of coordinated attention on language development across different operationalizations and study designs.

Results of significance tests for the reported effect sizes of RJA and IJA across vocabulary (Fig. 4) and study design variables are provided in Table 3. The only group which was not found to be significantly greater than 0 was the concurrent IJA group, which may be due to this group’s small sample size (n = 12). Regardless, the significance of ESCS coordinated attention measures in the development of language is validated by the observed significance in our remaining groups. Further, we did not observe any differences in the effect sizes across RJA and IJA in our 2 Sample t-tests for any variable group.

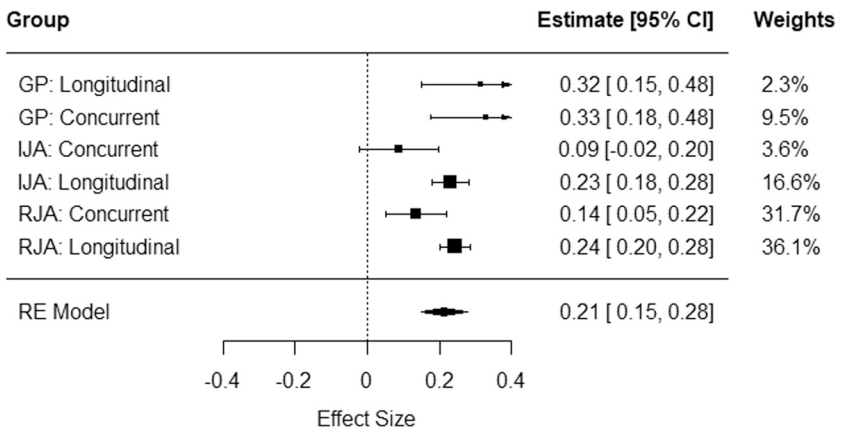


Fig. 3 Forest plot comparing pooled concurrent and longitudinal effect sizes by operationalization groups.

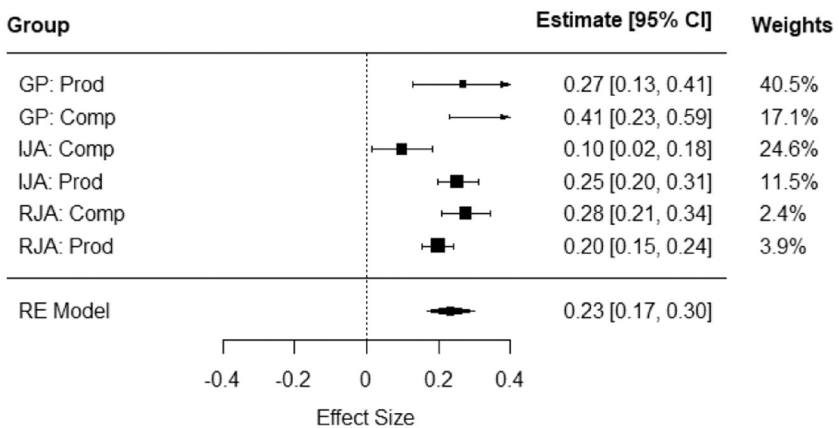


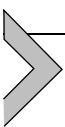
Fig. 4 Forest plot comparing pooled productive/comprehension vocabulary effect sizes by operationalization groups.

Table 3 Results of T-tests for significance and comparison of IJA and RJA group effect sizes.

Group	RJA t-value	IJA t-value	2 Sample t-test
Productive	5.53***	6.51***	0.10
Comprehension	7.38***	2.26*	0.08
Longitudinal	7.79***	6.69***	0.99
Concurrent	3.14**	1.78	0.77
Total	23.82***	17.24***	1.95

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

A summary of results provided by significance tests for the found effect sizes for GP and ESCS operationalizations across vocabulary and study design groups is provided in Table 4. All groups, except for concurrent gaze patterns, were significantly greater than 0. Effect sizes for ESCS were significantly greater than those reported for gaze pattern in total and across productive vocabulary and longitudinal groups. This suggests that ESCS may be a more robust measure of coordinated attention as it relates to language production than gaze pattern operationalizations of coordinated attention and provides further evidence that longitudinal designs are useful for examining the relations between of coordinated attention on language production.



10. Longitudinal relationships

This set of analyses focused on categorizing longitudinal designs into distinct age-based cohorts. These cohorts were determined to ensure a balanced distribution of studies and to correspond with the typical ages at which key language and motor milestones occur in children. The focal point of this set of analyses was the age at which coordinated attention was assessed, as the primary objective was to better understand the developmental window during which coordinated attention is a potent predictor of subsequent language abilities.

With a total of 339 longitudinal effect sizes included, the meta-analysis incorporated a random-effects model to estimate the overall effect and account for between-study heterogeneity. The calculated tau-squared (τ^2)

Table 4 Results of T-tests for significance and comparison of ESCS and GP group effect sizes.

Group	ESCS	Gaze pattern	2 Sample T-test
Productive	8.26***	3.19**	4.67***
Comprehension	6.59***	10.07***	-0.410
Longitudinal	10.45***	8.27***	3.04**
Concurrent	3.44**	1.89	1.67
Total	10.40***	8.22***	3.03**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

value of 0.02, with a standard error of 0.0049, and the I^2 statistic of 34.39% pointed to a moderate degree of variability among the studies due to heterogeneity rather than chance. The heterogeneity test yielded a Q value ($df = 338$) of 531.47 ($p < 0.0001$), suggesting significant variability across the included studies.

The model results presented a pooled estimate effect size of 0.19 with a standard error of 0.01, and a significant z-value of 13.25 ($p < 0.0001$). The 95% confidence intervals for this effect size ranged from 0.16 to 0.21, underscoring a significant association between coordinated attention and later language development across the examined age ranges. The forest plot comparing pooled effect sizes by age group when the coordinated attention variable measured (Fig. 5), showed a significant overall effect among the age groups. The “<8” months category exhibited the largest effect size (MD = 0.47, 95% CI [0.19, 0.76]), suggesting predictive power of coordinated attention on language development is particularly pronounced at the earliest ages assessed. In contrast, the “≥23” months category presented a notably smaller effect size (MD = 0.04, 95% CI [-0.22, 0.29]), indicating a reduced association between coordinated attention and language outcomes as age increases. This trend across age groups underscores a critical window during which coordinated attention is perhaps more influential on language development. The forest plot (Fig. 5) and bubble plot (Fig. 6) visualizations further visualized the effect sizes across age groups, highlighting the nuanced relationship between the timing of coordinated attention assessment and the magnitude of its predictive power on language development.

When examining the longitudinal relationship between coordinated attention and language development, we were primarily interested in the

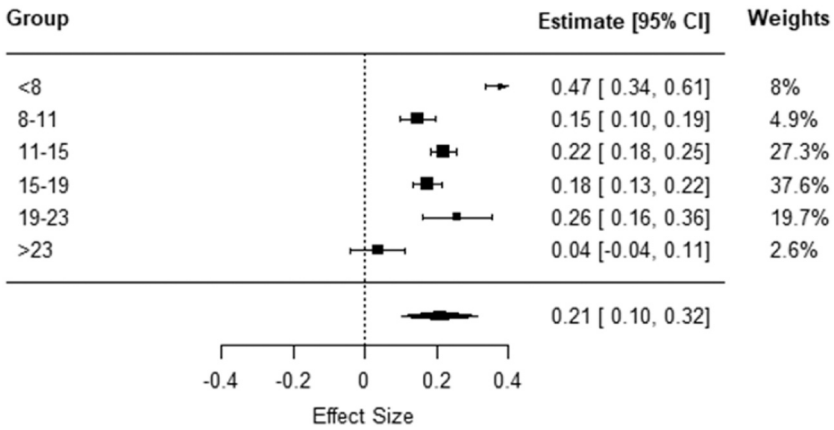


Fig. 5 Forest plot comparing pooled reported effect sizes by age group of coordinated attention variable measurement.

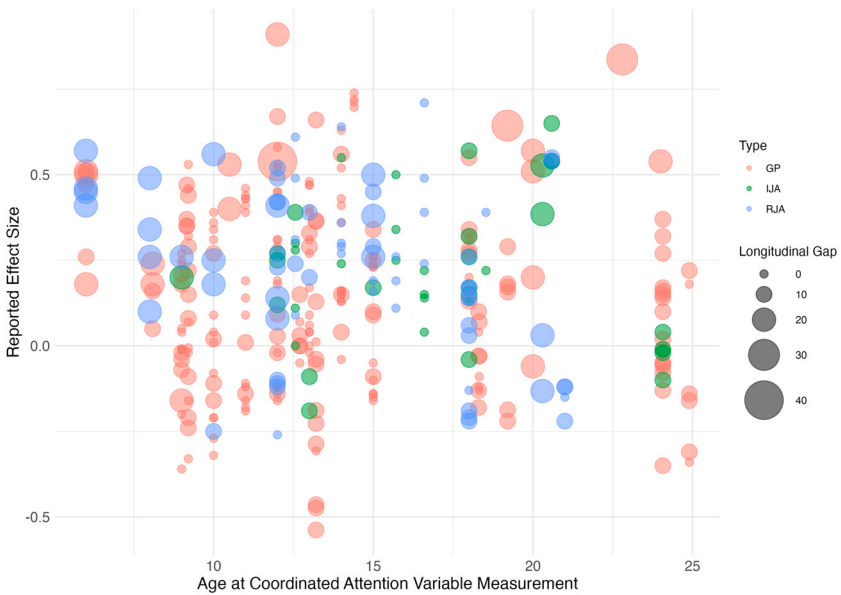


Fig. 6 Bubble plot displaying the relationship between effect size, age at coordinated attention variable measurement (months), and experiment variable measurement gap.

effect of (1) the age of coordinated attention measurement; and (2) the length of time or longitudinal gap between the measurement of coordinated attention and the measurement of vocabulary on the reported effect size. As with our other analyses, we wanted to investigate these trends

across coordinated attention operationalization group, given the observed difference in outcomes associated with these groups. To visualize the differences in effect size based on these variables simultaneously, we created a bubble plot (Fig. 6), which we mapped the age of coordinated attention measurement on the x-axis to the found effect size on the y-axis. The relative size of the “bubbles” corresponds to the length of the longitudinal gap for the effect size, and the color corresponds to the coordinated attention operationalization group.

To further explore the relationship between coordinated attention operationalization and longitudinal study design in a more quantifiable manner, we carried out a series of meta-regressions with (1) age of coordinated attention measurement and the (2) longitudinal gap in age between coordinated attention and vocabulary measurement as moderators of the effect size for each operationalization group. A summary of the results of these meta-regressions is provided in Table 5. We found the age of coordinated attention measurement to be a significant moderator for all longitudinal effects and for RJA only, with a greater significance level found for RJA suggesting that RJA may be driving the trend observed across all longitudinal effects for age of JA measurement. The relation between coordinated attention and language development was stronger the earlier the age when coordinated attention was measured.

For longitudinal gap, significant effects were found for all longitudinal effects and for gaze pattern. Again, the significance level was greater for gaze pattern, suggesting that it may be driving the effect of longitudinal gap that was observed for all longitudinal effects. The relation between coordinated attention and language development was stronger when the longitudinal gap was longer.

Table 5 Results of meta-regressions on group effect size using longitudinal gap as a moderator.

Group	Age coef. β (SE)	Longitudinal gap coef. β (SE)
All long. effects	-0.0069 (0.0028)*	0.0050 (0.0021)*
Gaze pattern	-0.0019 (0.0023)	0.0064 (0.0024)**
IJA	0.0182 (0.0182)	0.0060 (0.0055)
RJA	-0.0180 (0.0055)**	0.0030 (0.0033)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$



11. Publication bias

In meta-analyses, we must consider the bias introduced by the publication status of the studies included. Published studies are more likely to be statistically significant than unpublished studies, which may cause meta-analyses to produce larger effects than would be true of all studies, published and unpublished.

Of the 464 effect sizes included in our analyses, 81 were extracted from unpublished literature. A meta-regression of effect size with publication status as a moderator revealed that publication does moderate our data ($\beta = -0.07, p = 0.009$). However, the negative sign of our β -value indicated that being published was negatively associated with effect sizes in our dataset, with published studies having a substantially higher estimate ($\beta = 0.15, p < 0.001$) than unpublished studies ($\beta = 0.22, p < 0.001$), which is the opposite of the relationship that is expected in the presence of publication bias.

To further assess publication bias, we visualized this bias using funnel plots. We created the funnel plots with Fisher's Z transformed Pearson r correlation values on the x-axis and standard error on the y-axis. In the absence of publication bias, the points in a funnel plot should customarily form a symmetric "funnel" shape, wherein larger studies, which have lower standard error, should have lower variability and thus be closer to the true population effect size, and fill out the top, pointed region of the funnel. Smaller studies, which have higher standard error, are expected to have more variability, and fill out the larger, bottom portion of the funnel.

We constructed three funnel plots which separately reflect all included studies (Fig. 7), only studies which included ESCS as their operationalization of coordinated attention (Fig. 8), and only studies which operationalized coordinated attention using gaze patterns (Fig. 9). All three plots appear roughly symmetrical, suggesting that significant publication bias was not present in our dataset, regardless of coordinated attention operationalization.

To examine these observations more quantitatively, Egger's tests were performed for each dataset explored by our funnel plots (Egger, Davey Smith, Schneider, & Minder, 1997). The results were not significant for the full dataset (Egger Bias = 0.15, $p = 0.97$) nor the GP subset (Egger Bias = 1.66, $p = 0.10$) but were significant for the ESCS subset (Egger Bias = 2.42, $p = 0.02$). A further meta-regression was performed to assess the amount of publication bias present in the ESCS subset, using publication status as a

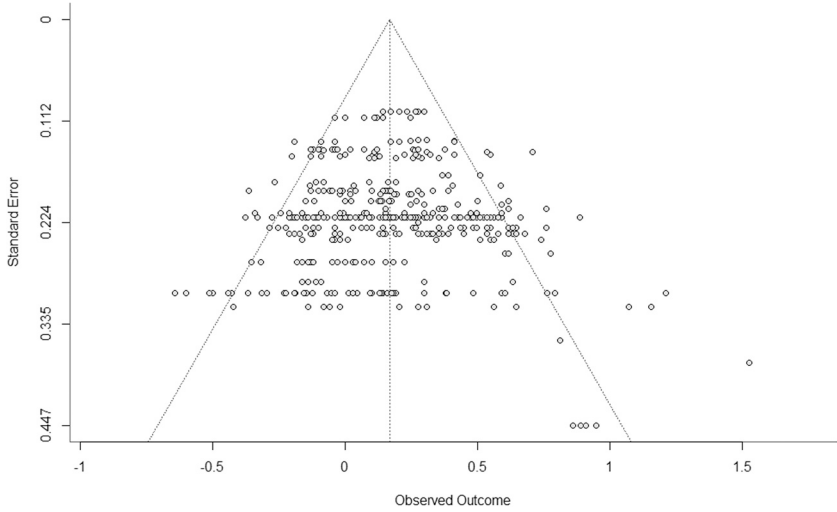


Fig. 7 Funnel plot with all effect sizes.

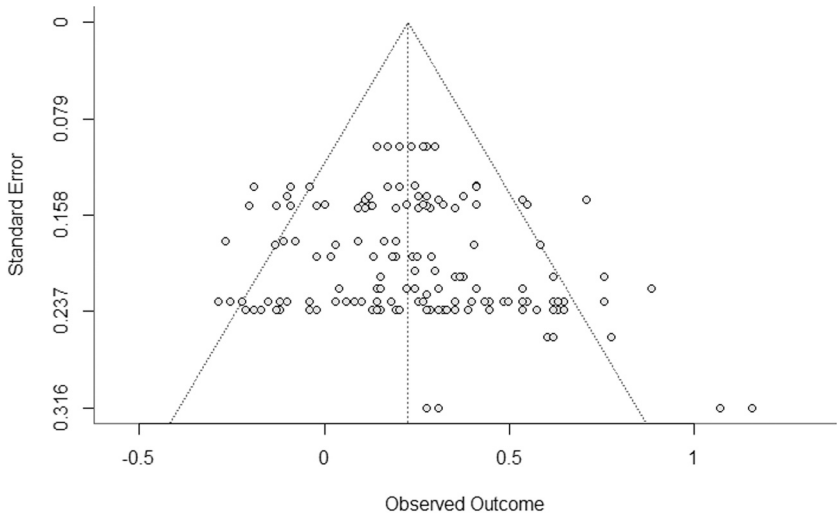


Fig. 8 Funnel plot of all ESCS group effect sizes.

moderator in only studies which used ESCS operationalization. This revealed a nonsignificant effect for publication status ($\beta = -0.06$, $p = 0.09$).

Our last test for publication bias within this meta-analysis was Rosenthal's fail-safe number (Rosenthal, 1995). Rosenthal's fail-safe number represents the minimum number of studies missing from a meta-analysis with non-significant

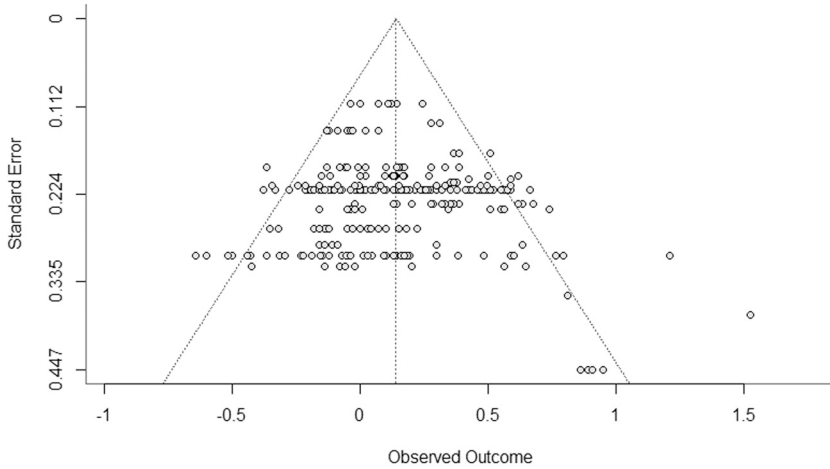


Fig. 9 Funnel plot of gaze pattern group effect sizes.

results required to decrease the findings of the present meta-analysis' findings to statistical insignificance. Meta-analyses are considered robust if the fail-safe number exceeds the critical value, as calculated by Rosenthal's formula ($5k + 10$), where k is the number of studies included in the meta-analysis. The Rosenthal's fail-safe number for our entire dataset of 46 studies was found to be 5766 ($p < 0.0001$). This is considerably larger than the critical value of 240, validating the robustness of the current meta-analysis, and suggesting that our data lacks publication bias.



12. Discussion

This meta-analysis provided a comprehensive overview of the relations between coordinated attention and language development throughout the first few years of life. From a systematic examination of 46 studies involving 1482 participants, we analyzed a total of 464 effect sizes. Across the different operationalizations of coordinated attention, ages of the infants, and language assessment type, we observed robust effect sizes suggesting a positive relation between coordinated attention and language ability: higher amounts of coordinated attention related to higher scores on a language assessment. Despite observing strong positive relationships across all of the studies included in this meta-analysis, there are some interesting observations that add important nuances to the collection of studies.

When looking into ESCS operationalizations of coordinated attention, Initiating Joint Attention (IJA) and Responding to Joint Attention (RJA) played significant roles in language development, with a marginal difference in effect sizes favoring RJA, although not statistically significant. These results suggest a comparable influence of both types of coordinated attention, despite how researchers generally interpret the differing functions of IJA and RJA during social interactions. Both ESCS and gaze pattern operationalizations had significant positive relations with productive language abilities. However, we also observed that the relation between ESCS operationalizations of coordinated attention and language comprehension had stronger positive effect sizes compared to gaze pattern operationalizations. Alternatively, the relation between gaze pattern operationalizations and comprehension language abilities was only nominally stronger than for ESCS operationalizations: both operationalizations had significant positive relations with comprehensions language abilities.

Breaking down the meta-analytic tests to focus on longitudinal research designs provided even more nuance about (1) how the age of when coordinated attention was measured and also (2) how the duration of the longitudinal gap between coordinated attention measurement and when the language assessment was completed impact the relations. A meta-regression with age when coordinated attention was measured as a moderator, showed that the relation between coordinated attention and language ability was stronger when coordinated attention was measured at earlier ages. A reasonable explanation for this result is that, at earlier ages, there is more variability in coordinated attention, and this variability is not noise but rather signal for the pathways toward increased language development (Abney et al., 2020). Another meta-regression with longitudinal gap as a moderator showed that the relation between coordinated attention and language ability was stronger when the longitudinal gap was longer. This result is surprising given that we would expect that concurrent measurements and short longitudinal gaps would explain more variability of behaviors and abilities. Given the combination of the result of this meta-regression and the result that the only significant pooled effect sizes for the relation between operationalization and language abilities was for ESCS operationalizations, and not for gaze pattern operationalizations, it is possible that the properties of how ESCS is operationalized is explaining important variability of future language abilities. For example, given that ESCS coding includes an assessment of intentionality or social awareness, it is possible that these ‘social’ properties explain variability of future language abilities.

Despite the potential for publication bias, various analytical methods, including funnel plots, Egger's test, and Rosenthal's fail-safe number, confirmed the robustness of these findings. The moderate heterogeneity observed across studies points to a consistent, yet varied, relation between coordinated attention and language development.

In conclusion, although we observed robust pooled effect sizes across all of the studies included in this meta-analysis, we did find interesting differences when looking at various properties of operationalizations, experimental design, and language assessments. Despite some of the perceived strong contrasts between how coordinated attention is operationalized and subsequently measured, all these efforts to better understand the dynamics of visual attention across infants and their caregivers appear to be tapping into the same developmental phenomenology. The results from this meta-analysis will hopefully inspire future researchers to better understand the differing properties of operationalizations of coordinated attention that influenced some of the nuanced results that were observed across operationalizations, experimental design, and language assessments.

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