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Inferring signed networks from preschoolers' observed parallel and social play[☆]

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ABSTRACT

Early childhood is an important developmental period for network formation. However, the observational methods used for measuring young children's networks present challenges for capturing both positive and negative ties. To overcome these challenges, we explored the use of a bipartite projection backbone model for inferring both negative and positive ties from observational data of children's play. Using observational data collected in one 3-year-old (N = 17) and one 4-year-old (N = 18) preschool classroom, we examined whether patterns of homophily, triadic closure, and balance in networks inferred using this method matched theoretical and empirical expectations from the early childhood literature. Consistent with this literature, we found that signed networks inferred using a backbone model exhibited gender homophily in positive ties and gender heterophily in negative ties. Additionally, networks inferred from social play exhibited more closed and balanced triads than networks inferred from parallel play. These findings offer evidence of the validity of bipartite projection backbone models for inferring signed networks from preschoolers' observed play.

1. Introduction

Preschool offers an initial opportunity for young children to form both positive and negative social ties with same-age peers (e.g., Daniel et al., 2016; Irwin et al., 2021; Martin et al., 2005; Schaefer et al., 2010). However, studies of networks in early childhood are rare (Neal, 2020a) and only a handful of these studies have examined signed networks that include both positive and negative ties (e.g., Daniel et al., 2016; Van den Oord et al., 2000). Because self-report methods are difficult to use with young children, researchers have often measured early childhood networks using scan observational methods that focus on affiliation behaviors such as play (e.g., DeLay et al., 2016; Neal, 2020a; Schaefer et al., 2010; Strayer and Santos, 1996). These observational methods present challenges for capturing both positive and negative ties between children. It is not always clear how many times a pair of children need to be observed playing together to warrant concluding that the pair have a positive tie. Additionally, it is not always clear how few times a pair of children need to be observed playing together to infer that the pair have a negative tie (i.e., are avoiding one another).

To overcome these challenges, we explored the use of a bipartite projection backbone model for inferring both negative and positive ties from observational data of children's play. We found that patterns of homophily, triadic closure, and balance in networks inferred using this method matched theoretical and empirical expectations from the early childhood literature. Specifically, consistent with gender schema theory and gendered patterns of play (e.g., Martin and Halverson, 1981; Martin and Ruble, 2004; Martin et al., 2013; Daniel et al., 2016; Van den Oord et al., 2000), our inferred signed networks exhibited gender homophily in positive ties and gender heterophily in negative ties. Additionally, consistent with theoretical expectations about levels of coordination required for different types of play (e.g., Parten, 1932; Coplan and Arbeau, 2009), networks inferred from social play exhibited more closed and balanced triads than networks inferred from parallel play. These findings offer evidence of the validity of bipartite projection backbone models for inferring signed networks from preschoolers' observed play.

We begin by providing a brief review of the literature on networks in early childhood, including literature on measurement challenges as well as theoretical and empirical expectations for patterns of homophily, triadic closure, and balance. Next, we describe the use of one bipartite projection backbone model – the fixed degree sequence model – for inferring signed networks from observations of children's parallel and social play. Using observational data collected in two preschool

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classrooms, we offer evidence for the validity of this method by demonstrating that patterns of homophily, triadic closure, and balance are consistent with theoretical expectations based on gender and type of play. Finally, we end with implications for understanding networks in early childhood and future directions for research.

2. Background

Early childhood is an important developmental period for the formation of both positive and negative ties (Daniel et al., 2016). In the U.S. and in other countries, it is common for young children to enroll in preschool, providing one of the first opportunities for extended social interactions with other same-age peers (e.g., Daniel et al., 2016; Irwin et al., 2021; Martin et al., 2005; Schaefer et al., 2010). During this period, young children begin to engage in more complex and coordinated forms of play (Coplan and Arbeau, 2009; Göncü et al., 2002) and form networks with standard structural features like reciprocity and transitivity (Daniel et al., 2013, 2016; Schaefer et al., 2010). These networks can influence children's personality traits (e.g., Neal et al., 2017), preschool competency (e.g., DeLay et al., 2016), and engagement in gender stereotypical activities (e.g., Martin et al., 2013).

Although early childhood is an important developmental period, fewer network studies have been conducted during this period than in middle childhood or adolescence. In a recent systematic review of developmental psychology articles using networks, only 4% included samples ages 0 to 4 (Neal, 2020a). Researchers may be less likely to examine networks in early childhood because the self-report name generators typically used to collect network data (see adams, 2020) are developmentally challenging to use with young children. Unlike older children and adolescents, young children typically require extra supports when completing these self-report name generators including pictures of all of the children within the specified network boundary (e.g., class, school). Children either sort or point to these pictures in response to the self-report name generator (e.g., Daniel et al., 2016; McCandless and Marshall, 1957; Van den Oord et al., 2000). In the United States, self-report methods may also not be feasible when measuring negative ties because educators, parents, and university institutional review boards are often reluctant to allow researchers to use name generators focused on negative ties with young children.

Because self-report name generators are difficult to use with young children, researchers have typically used more time-intensive scan observational methods to measure networks in early childhood (e.g., Daniel et al., 2019; DeLay et al., 2016; Hanish et al., 2005; Neal et al., 2017; Schaefer et al., 2010). However, there are two major challenges to using observational approaches to measure young children's networks. First, it is not always clear how many times two children must be observed interacting to warrant inferring they have a positive network tie. Schaefer et al. (2010), Daniel et al. (2013, 2019), and Neal et al. (2017) have all proposed solutions, but none offer a formal statistical test. Second, it is also challenging to observe negative interactions, particularly among young children. Although some prior work has focused on directly observable negative interactions in preschool such as overt displays of negative affect, physical aggression, or conflict, these interactions often occur at low rates and are disrupted by teachers (Roseth et al., 2008; Vaughn et al., 2003). In these cases, observing children for longer periods of time can help (e.g., Ostrov and Keating, 2004), but is even more time and labor intensive. More subtle negative ties such as avoidance are also challenging to directly observe because they often do not involve overt behaviors. Here, it is not always clear how few times two children must be observed interacting to warrant inferring that they have a negative tie.

In this paper, we explored bipartite projection backbone models as a possible solution to these challenges (Neal, 2014). These models test the statistical significance of edges in weighted bipartite projections, and yield a new simpler 'backbone' network that contains only the significant edges. The data collected via scan observational methods can be viewed as a two-mode or bipartite network when they are organized as a binary child-by-play event matrix $\mathbf{M}$, where $M_{ik} = 1$ if child i was observed participating in a play event k. The bipartite projection of these data takes the form of a weighted co-playing network in which two children are connected to the extent that they were observed playing together. When applied to such a bipartite projection, backbone models offer a formal statistical testing framework for inferring, on the basis of observed co-playing, whether two children have a positive network tie. Moreover, they can also be used to infer, on the basis of observations of *not* playing together, whether two children are avoiding one another and thus have a negative network tie.

We were interested in whether a network inferred from scan observational data using a backbone model validly measures the network among preschool children. One way to provide evidence of the validity of a measurement approach involves examining whether the measurement yields theoretically and empirically expected patterns (Cronbach and Meehl, 1955; Messick, 1995). To generate this type of evidence of validity, here we examine whether the inferred network exhibits structural patterns that are theoretically expected and have previously been empirically observed among preschool children. In the remainder of this section, we review patterns rooted in gender- and play-differences that offer concrete expectations, and thus which can be used to evaluate the validity of the network inferences.

2.1. Gender and play in early childhood

Gender structures children's social ties from an early age. By preschool, children exhibit strong preferences for same gender peers and networks of positive ties exhibit notable gender homophily (e.g., Chen et al., 2020; Daniel et al., 2016; Martin et al., 2005, 2013; Schaefer et al., 2010; Van den Oord et al., 2000). In contrast, negative ties in early childhood tend to exhibit gender heterophily. Preschool children are more likely to indicate that they dislike playing with different-gender peers, and this dislike increases between ages 3 and 5 (Daniel et al., 2016; Van den Oord et al., 2000).

Gender patterns in networks during early childhood are driven by multiple mechanisms. First, children may exhibit direct preferences for playing with same gender peers (Maccoby, 1990; Maccoby and Jacklin, 1987; Martin and Ruble, 2010; Martin et al., 2011). These preferences can be explained by gender schema theory which suggests that young children make assumptions about the characteristics of boys and girls and view same-gender peers as more similar to themselves (Martin and Halverson, 1981; Martin and Ruble, 2004). Second, boys and girls may prefer to participate in distinct gender-typed activities during play (e.g., playing with trucks vs. dolls), which might indirectly lead to gender homophily in positive ties and gender heterophily in negative ties (Goble et al., 2012; La Freniere et al., 1984; Martin and Fabes, 2001; Martin et al., 2011, 2013).

We can offer evidence of the validity of backbone models for inferring negative and positive ties in preschoolers' observed play by examining whether gender patterns conform to established theories and prior empirical findings. *If backbone models validly infer young children's networks, positive ties derived from these models should more often occur between same gender peers and negative ties derived from these models should more often occur between peers of different genders.*

2.2. Types of play in early childhood

During preschool, children commonly participate in multiple forms of play including parallel play and social play (Coplan and Arbeau, 2009; Luckey and Fabes, 2005; Parten, 1932). Parallel play occurs when a child passively participates in the same activities as a nearby peer or set of peers but does not engage in conversation or interactions with them. For example, two children who are silently building their own block towers next to each other would be engaged in parallel play. In contrast, social play occurs when a child actively participates in direct interactions such as social conversations, sharing toys, or pretend play with a peer or set of peers. For example, two children who are working together to build the same block tower by sharing blocks and discussing what to build next would be engaged in social play.

Networks reflecting parallel play and social play may differ in structure. As Parten (1932) noted parallel play involves "playing *beside* rather than *with* the other children" (p. 250). By definition, parallel play does not involve any direct social interactions with peers, and therefore patterns of co-parallel play may be driven more by opportunity than by coordination. In contrast, social play is characterized by social interactions that are often complex and involve coordination between peers (e.g., sharing, division of labor; Coplan and Arbeau, 2009). Because social play involves coordination between peers, networks derived from social play observations should contain more structures that suggest coordination, while networks derived from parallel play observations should contain fewer such structures.

One network structure that can require coordination to form is *triadic closure*. In a dynamic context, triadic closure occurs when open triads of the form A–B–C (what Granovetter (1973) calls 'forbidden triads') become closed triads because a network tie forms between A and C. There are several mechanisms that might induce triadic closure, including brokerage (e.g., B introduces A to C), homophily (e.g., A and C have similar interests, namely B), and co-presence (e.g., A and C are in the same place at the same time when they are with B). The effects of triadic closure are reflected in static networks when a large fraction of connected triples are also triangles (i.e. high transitivity). While triad closure is common in most networks, it is also known to be common and to increase over time specifically among preschool children (e.g., liking, social play; Daniel et al., 2016, 2019; Schaefer et al., 2010; Van den Oord et al., 2000). Because social play involves more coordination than parallel play, *if backbone models validly infer young children's networks, we would expect networks inferred from social play to exhibit more transitivity than networks inferred from parallel play.*

A second network structure that can require coordination to form is *balance*. In a signed network, a triangle is (classically) balanced when the product of the positive (+) and negative (−) ties is positive (Cartwright and Harary, 1956). More conceptually, balance occurs when actors form positive and negative ties in patterns that obey a set of aphoristic rules such as "a friend of a friend is a friend" and "an enemy of an enemy is a friend" (Doreian et al., 1996, p. 115) that find their origins in the sociology of Simmel and psychology of Heider (Krackhardt and Handcock, 2006). In a dynamic context, balance increases locally as actors re-arrange their social ties to achieve greater balance in their own social circles, and globally because unbalanced triads are inherently unstable (Doreian et al., 1996). The effects of tendencies toward balance are reflected in static networks when a large fraction of signed triangles are balanced (i.e., a high triangle index; Aref and Wilson, 2018). To date, few studies have investigated balance in preschoolers' networks mainly because signed networks are challenging to collect from this population. Daniel et al. (2016) did not find evidence of balance in preschoolers' self-reported affect toward others. However, this study focused on psychological balance, whereas our focus is on balance in social interactions. Again, because social play involves more coordination than parallel play, *if backbone models validly infer young children's networks, we would expect networks inferred from social play to exhibit more balance than networks inferred from parallel play.*

3. Method

3.1. Setting and sample

To provide evidence of the validity of bipartite projection backbone models for inferring young children's signed networks, we used observational data collected in one 3-year-old and one 4-year-old preschool classroom. Both classrooms were part of a university preschool located in the U.S. Midwest that serves children and families from the surrounding community. Children in these classrooms attended preschool in the morning between 8:30 and 11:30 am and received a curriculum that included both structured activities with teachers as well as periods of unstructured free play. During free play periods, children chose their own activities and playmates. Both classrooms included roughly equal numbers of students (i.e., 3-year-old classroom $N = 17$, 4-year-old classroom $N = 18$). Demographics for children in each classroom including gender, race/ethnicity, and age are provided in Table 1.

Table 1
Sample demographics & observations.

	3-year-old (N = 17)	4-year-old (N = 18)
Gender		
Boy	8 (47.06%)	9 (50%)
Girl	9 (52.94%)	9 (50%)
Race/Ethnicity		
Asian	3 (17.65%)	0 (0%)
Black/African American	3 (17.65%)	0 (0%)
White	8 (47.06%)	14 (77.78%)
Multi-racial/Multi-ethnic	1 (5.88%)	1 (5.55%)
Missing	2 (11.76%)	3 (16.67%)
Age (in months), M(SD)	42.35 (4.74)	51.78 (3.57)
Observations		
Social play	668	994
Parallel play	434	423

3.2. Procedure

Between October 2012 and May 2013, we collected data on children's gender from preschool staff and data on parallel play and social play interactions using scan observational procedures similar to those applied in previous preschool studies (e.g., Daniel et al., 2019; Hanish et al., 2005; Schaefer et al., 2010). During each classroom observational period, an observer received a randomly ordered list of children and pictures identifying each child in the classroom. The observer rotated through the list, observing each child for a period of 10 s and recording their most dominant behavior from a list of 7 behaviors (i.e., parallel play, social play, rough and tumble play, onlooking behavior, solitary play, unoccupied behavior, and teacher-oriented behavior). When a behavior involved interactions with peers (e.g., parallel play, social play), the observer also coded the identities of all peers engaged in the interaction.

A team of trained observers conducted observations on Mondays through Thursdays. Observations were scheduled during periods of unstructured free play to ensure that observations reflected children's autonomous choice of playmates. In the 3-year-old classroom, observers collected a total of 1102 scan observations involving parallel play (n = 434) or social play (n = 668). In the 4-year-old classroom, observers collected a total of 1417 scan observations involving parallel play (n = 423) or social play (n = 994). In addition to these 2519 observations which we use to infer children's networks with methods described below, pairs of observers also recorded observations of the same focal child 216 times to evaluate the reliability of these observations. In these reliability-check observations, observers agreed on the observed behavior 79.89% of the time ($\kappa = 0.661$, $p < 0.001$), and on the exact set of peers involved in social or parallel play 81.94% of the time ($\kappa = 0.816$, $p < 0.001$).

All procedures were approved by the authors' institutional review board (Protocol 11-1198). Because observations of classroom social interactions posed minimal risk to children and could not be conducted without observing all children in the classroom, we received a waiver of active parental consent and student assent (Klovdahl, 2005). This ensured that we were able to collect data on all children and all social interactions in each classroom.

3.3. Signed network inference

Within each classroom, we organized the scan observation data in a matrix $\mathbf{M}$, which represents a bipartite network where $M_{ik} = 1$ if child i was observed participating in a play event k. From this matrix, a weighted bipartite projection $\mathbf{P}$ can be constructed as $\mathbf{P} = \mathbf{MM}'$, where P_{ij} records the number of times children i and j were observed playing together. Such a co-playing network is not very useful because nearly every pair of children was observed playing together at least a few times. Bipartite projection backbone models provide a test for determining whether the number of times two children were observed playing together (i.e., P_{ij}) was statistically significantly *larger* than expected at random and therefore suggestive of a *positive* social tie, or was statistically significantly *smaller* than expected and therefore suggestive of a *negative* social tie.

Many different bipartite projection backbone models are available, but here we used the fixed degree sequence model (FDSM) implemented in the 'backbone' package (Neal, 2022) because it is more statistically powerful than the alternatives (Neal et al., 2021). The mathematical details of the FDSM have been extensively described elsewhere (e.g., Gotelli, 2000; Zweig and Kaufmann, 2011; Neal et al., 2021), so here we briefly outline the process. A Monte Carlo method was required to determine whether P_{ij} is statistically significantly large or small. First, a random bipartite matrix $\mathbf{M}^*$ was constructed that has the same row and column sums as $\mathbf{M}$. Second, a random projection $\mathbf{P}^*$ was constructed from $\mathbf{M}^*$ as $\mathbf{P}^* = \mathbf{M}^*\mathbf{M}^{*\prime}$. This process was repeated many times to obtain a distribution of P^*_{ij}, to which P_{ij} was compared using a chosen level of statistical significance (α). Applying this statistical test to each dyad, a signed network $\mathbf{S}$ was inferred such that

$$S_{ij} = \begin{cases} 1 \text{ (i.e., positive tie)} & \text{if } \Pr(P^*_{ij} \geq P_{ij}) < \frac{\alpha}{2}, \\ -1 \text{ (i.e., negative tie)} & \text{if } \Pr(P^*_{ij} \leq P_{ij}) < \frac{\alpha}{2}, \\ 0 \text{ (i.e., no tie)} & \text{otherwise.} \end{cases}$$

We used a conventional $\alpha = 0.05$ significance level to infer whether a given dyad had a positive tie, a negative tie, or no tie. In practice, this requires computing $\Pr(P^*_{ij} \geq P_{ij})$ and $\Pr(P^*_{ij} \leq P_{ij})$ with sufficient precision to be confident in any decisions that it is smaller than 0.025 (i.e., $\alpha/2$). Using the estimation provided by Neal et al. (2021), we found that making such decisions with 5% Type-I error and 5% Type-II error (i.e., 95% Power) required $\approx 165{,}000$ trials. This highlights a key practical challenge to using FDSM: efficiently generating $\mathbf{M}^*$ such a large number of times. To overcome this challenge, we used the 'fastball' algorithm, which has been proven to randomly sample $\mathbf{M}^*$ from the space of all binary matrices with given row and column sums (Godard and Neal, 2021).

The FDSM is a generic model for inferring a signed (or binary) unipartite network from a weighted bipartite projection. When applied in this context, it allowed us to infer a signed network of social ties among preschool children from their observed play behaviors. These inferences depend on whether the number of times two children were observed playing together was significantly larger (a positive tie is inferred) or smaller (a negative tie is inferred) than the number of times they would be observed playing together if they selected play partners randomly. However, rather than simply judging whether the number of co-playing observations was large or small in absolute terms, the FDSM allowed us to take into account the fact that children differed in how often they play with others (i.e., sociability), and play groups differed in their numbers of participants. For each classroom, we used the FDSM to infer a network from all social and parallel play observations, which we used to test hypotheses concerning gender homophily. We then used it to infer separate networks from social play behaviors and from parallel play behaviors, which we used to test hypotheses concerning triadic closure and structural balance. All data and code necessary to replicate these analyses is available at https://osf.io/q7nh6.

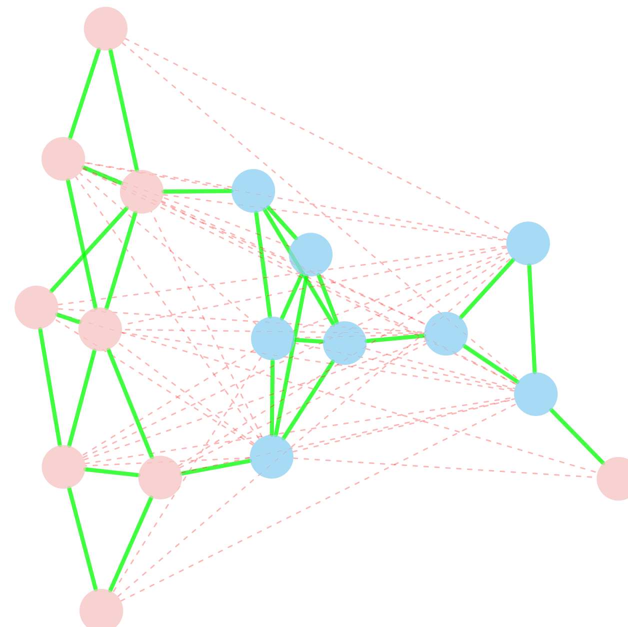

Fig. 1. Signed network inferred from observed play behaviors of 3-year-old girls (pink) and boys (blue). Solid green lines represent positive ties, while dashed red lines represent negative ties. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

4. Results

4.1. Inferred signed networks

To illustrate the types of signed networks this approach is able to infer from scan observation data, Fig. 1 shows the network inferred from all social and parallel play observations in the 3-year-old classroom, and Fig. 2 shows the network inferred in the 4-year-old classroom. Pink circles represent girls and blue circles represent boys. Solid green lines represent pairs of children who played together statistically significantly more than expected at random, which we treated as positive ties. There were 29 positive ties in the 3-year-old classroom and 31 positive ties in the 4-year-old classroom. In contrast, dashed red lines represent pairs of children who played together statistically significantly less than expected at random, which we treated as negative ties. There were 38 negative ties in the 3-year-old classroom and 54 negative ties in the 4-year-old classroom. Both sociograms were drawn by applying the (Kamada and Kawai, 1989) layout to the positive edges only.

The inferred networks contain more negative ties than positive ties, which is consistent with other applications of bipartite projection backbone models (e.g., Neal, 2020b; Aref and Neal, 2020). This may seem unusual. However, it is important to remember that the inferred edges do not measure affective valence, but instead measure affiliation and avoidance. In any social setting, an individual will tend to affiliate with just a few others, which is why the density and mean degree of social networks tends to be low. This leaves everyone else in the setting (typically a large number) as candidates for avoidance. Therefore, it is intuitive and expected that positive ties would be rare compared to negative ties when they are operationalized as affiliation and avoidance, respectively.

4.2. Gender homophily

To provide evidence of the validity of our inferred networks, we first examined patterns of gender homophily and heterophily in the classroom networks inferred from all social and parallel play observations. If the backbone model validly inferred young children's signed

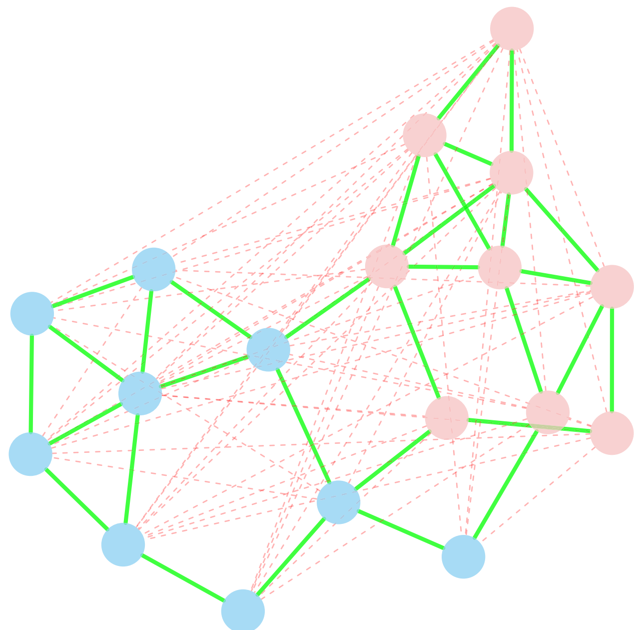

Fig. 2. Signed network inferred from observed play behaviors of 4-year-old girls (pink) and boys (blue). Solid green lines represent positive ties, while dashed red lines represent negative ties. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

Table 2
Gender homophily.

Tie	3-year-old dyads		4-year-old dyads	
	Different	Same	Different	Same
Positive	3 (10.3%)	26 (89.7%)	3 (9.7%)	28 (90.3%)
Negative	32 (84.2%)	6 (15.8%)	45 (83.3%)	9 (16.7%)
None	37 (53.6%)	32 (46.4%)	33 (48.5%)	35 (51.5%)
	Fisher's exact $p < 0.001$		Fisher's exact $p < 0.001$	

Table 3
Triadic closure.

Triad	3-year-old networks		4-year-old networks	
	Parallel play	Social play	Parallel play	Social play
Closed	15 (35.7%)	30 (50%)	6 (16.2%)	18 (24.7%)
Open	27 (64.3%)	30 (50%)	31 (83.8%)	55 (75.3%)
	Fisher's exact $p = 0.1634$		Fisher's exact $p = 0.342$	

social ties, then positive ties should occur more often in same-gender dyads, while negative ties should occur more often in different-gender dyads. These patterns of gender homophily and heterophily are clearly visible in both Figs. 1 and 2. They are corroborated in cross-tabulations reported in Table 2, which examined the relationship between the type of tie (i.e., positive, negative vs. none) and the gender composition of peer dyads (i.e., different-gender vs. same-gender). As expected, the majority of positive ties occurred in same-gender dyads in both the 3-year-old classroom (89.7%) and the 4-year-old classroom (90.3%). Likewise, the majority of negative ties occurred in different-gender dyads in both the 3-year-old classroom (84.2%) and the 4-year-old classroom (83.3%). These patterns of gender homophily in positive ties and gender heterophily in negative ties were statistically significant in both classrooms (Fisher's exact test $p < 0.001$).

One risk is that the inferred networks exhibited these expected gender homophily patterns because the inferences were simply driven by gender, such that most same-gender dyads were inferred to have a positive tie and most different-gender dyads were inferred to have a negative tie. However, the results in Table 2 demonstrate that this was not happening. Specifically, we observed that the backbone model frequently inferred that no tie exists in a dyad, and that it was equally likely to infer that no tie existed in same-gender and in different-gender dyads (46.4% vs. 53.6% among 3-year olds; 51.5% vs. 48.5% among 4-year-olds). This pattern indicates that backbone model inferences were able to distinguish same-gender dyads that have a positive tie from those that have no tie, and likewise to distinguish different-gender dyads that have a negative tie from those that have no tie.

Table 4
Structural balance.

Triad	3-year-old networks		4-year-old networks	
	Parallel play	Social play	Parallel play	Social play
Balanced	124 (77.5%)	244 (92.4%)	64 (76.2%)	452 (86.3%)
Unbalanced	36 (22.5%)	20 (7.6%)	20 (23.8%)	72 (13.7%)
	Fisher's exact $p < 0.001$		Fisher's exact $p = 0.02156$	

4.3. Triadic closure and structural balance

Using separate networks inferred from social play behaviors and from parallel play behaviors, we examined triadic closure. If the backbone model validly inferred young children's signed ties, then networks inferred from social play should exhibit more transitivity in positive ties than networks inferred from parallel play. Table 3 reports, for each classroom, the relationship between the type of network (i.e., parallel play vs. social play) and the type of triad (i.e., closed vs. open; using positive ties only). In these cross-tabulations, the reported percentage of closed triads reflects each network's transitivity. As expected, networks inferred from social play exhibited more transitivity than networks inferred from parallel play among 3-year-olds (50% for social play vs. 35.7% for parallel play) and among 4-year-olds (24.7% for social play vs. 16.2% for parallel play). However, in part due to the small cell counts, these differences were not statistically significantly different (Fisher's exact $p = 0.1634$ and $p = 0.342$).

Again using separate networks inferred from social play behaviors and from parallel play behaviors, we also examined balance. If the backbone model validly inferred young children's networks, then networks inferred from social play should exhibit more balance than networks inferred from parallel play. Table 4 reports, for each classroom, the relationship between the type of network (i.e., parallel play vs. social play) and the type of triad (i.e., balanced vs. unbalanced). In these cross-tabulations, the reported percentage of balanced triads reflects each network's triangle index, and thus its degree of classical balance. As expected, networks inferred from social play exhibited significantly more balance than networks inferred from parallel play among 3-year-olds (i.e., 92.4% for social play vs. 77.5% for parallel play, Fisher's exact $p < 0.001$) and among 4-year-olds (86.3% for social play vs. 76.2% for parallel play, Fisher's exact $p = 0.02156$).

5. Discussion

Although early childhood is a critical developmental period for the formation of social ties (e.g., Daniel et al., 2016; Irwin et al., 2021; Martin et al., 2005; Schaefer et al., 2010), studies of preschoolers' networks remain uncommon, in part, due to measurement challenges (Neal, 2020a). In this paper, we explored the use of a bipartite projection backbone model – the fixed degree sequence model – to infer positive and negative ties among preschoolers from observations of their play interactions. Using observational data from two preschool classrooms, we offered evidence of the validity of the inferred networks by demonstrating that they exhibit structural patterns that are consistent with existing theoretical and empirical expectations in the early childhood literature.

Using networks inferred from all social and parallel play observations, we found evidence of gender homophily in positive ties and gender heterophily in negative ties. These findings are consistent with gender schema theory which suggests that preschoolers form gender-based assumptions that prompt preferences for same gender playmates (Martin and Halverson, 1981; Martin and Ruble, 2004). They are also consistent with well-documented empirical evidence that preschool children tend to form positive ties with same gender peers (e.g., Chen et al., 2020; Daniel et al., 2016; Martin et al., 2013; Schaefer et al., 2010) and negative ties with peers of different genders (Daniel et al., 2016; Van den Oord et al., 2000). Additionally, using separate networks inferred from social play behaviors and from parallel play behaviors, we found networks inferred from social play exhibited more closed and balanced triads than networks inferred from parallel play. These findings are consistent with theoretical expectations that networks derived from social play, which includes active interactions, should contain more structures that suggest peer coordination than parallel play, which only includes passive interactions (Coplan and Arbeau, 2009; Parten, 1932).

As a set, our findings provide evidence of the validity of backbone models for inferring signed networks from play observations in early childhood. These models have benefits for measuring and understanding young children's social ties. First, developmental researchers have struggled with establishing criteria for inferring positive ties from children's play observations. As Daniel et al. (2013) noted, inferring positive ties from observational data "involves some degree of arbitrariness and at the moment there is not a generally accepted approach for doing so" (p. 26). Backbone models reduce this arbitrariness because they provide a formal statistical test of whether the number of times two children were observed playing together was significantly larger than expected at random. Second, negative ties are particularly challenging to measure among young children because they are low rate, difficult to collect via self-report, and challenging to directly observe (Roseth et al., 2008; Vaughn et al., 2003). Backbone models provide a method of inferring negative ties because they provide a formal statistical test of whether the number of times two children were observed playing together was significantly smaller than expected at random. Thus, bipartite projection backbone models open new possibilities for developmental researchers to examine signed networks in early childhood. Although we have focused on preschool children, these methods may also open similar possibilities for other populations from whom self-report networks are challenging to collect (e.g., adults with developmental disabilities or memory impairments).

Our results provide initial evidence of the validity of backbone models for inferring signed networks among young children but should be interpreted in light of some limitations. Because collecting observational data is resource intensive, we were only able to examine evidence for the validity of networks inferred in two classrooms at a Midwestern US university preschool. It is notable that our findings were similar across these classrooms despite differences in age (3-year-old vs 4-year-old) and racial/ethnic composition. However, future work is needed to determine whether these findings would generalize to different preschool settings and demographically and geographically diverse samples. Additionally, we were unable to collect self-report data on children's positive and negative ties. Future work could add to our evidence of validity by collecting both observational and self-report data, then examining whether networks inferred from observations resemble those reported by children. Finally, our evidence of validity comes from a series of relatively simple hypothesis tests that each evaluate the presence of one specific network property (homophily, closure, balance). Future studies relying on larger networks may more stringently test the validity of inferred networks by evaluating the presence of all these properties simultaneously, for example, using exponential random graph models.

This analysis also highlights some potential limitations of the backbone models themselves. First, these models require a large number of observations from which to infer social ties. In our case, we successfully inferred a network from as few as 423 observations (i.e., observations of parallel play in the 4-year-old classroom). However, conducting this number of observations may be impractical in some settings. Second, the fixed degree sequence model is computationally costly. In our case, 165,000 Monte Carlo trials were necessary, which required less than a minute. However, inferring networks using a more conservative significance level (i.e., $\alpha < 0.05$) would require more trials, and inferring networks from larger numbers of observations would require more time per trial. Alternative backbone models such as the stochastic degree sequence model are more efficient, however this efficiency comes at the cost of reduced statistical power (Neal et al., 2021).

These limitations notwithstanding, we have presented preliminary evidence of the validity of early childhood networks inferred from play observations using backbone models. This approach offers new opportunities for studying networks during the developmentally formative period of early childhood, and for understanding the role of both positive and negative ties on a range of social, cognitive, and health outcomes.

CRediT authorship contribution statement

Jennifer Watling Neal: Collected the data, Writing – original draft, Writing – review & editing. **Zachary P. Neal:** Analyzed the data, Writing – original draft, Writing – review & editing. **C. Emily Durbin:** Collected the data, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data and code necessary to replicate this study are available at https://osf.io/q7nh6.

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