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ARTICLE

Using behavioural network mapping to investigate dyadic play in girls with congenital adrenal hyperplasia

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Abstract
Examining mechanisms underlying sex differences in children's play styles, we studied girls with congenital adrenal hyperplasia (CAH) who provide a test of the relative effects of prenatal androgens versus rearing, and of behavioural similarity versus gender identity and cognitions. In this exploratory study, 40 focal children (girls and boys with and without CAH), aged 3–8 years, played for 14 min with a same-sex peer in a task designed to elicit rough-and-tumble play. Time-indexed ratings of positive affect and vigour of activity were evaluated via network mapping for sex-related differences in both levels and play dynamics (temporal relations among behaviours). Results suggest influences of both gender identity-aligned social cognitions and prenatal androgens: there was greater dyadic synchrony between positive affect for girls (regardless of CAH status) than boys, but girls with CAH displayed positive affect levels and directed vigorous peer play dynamics similar to boys.

KEYWORDS
biological development, gender, observational, peer behaviour, play, statistics

Gender plays a prominent role in children's lives, as described in other papers in this special issue. Gender has a particular role in children's play and social interactions (for reviews, see Blakemore et al., 2009; Leaper, 2015; Martin et al., 2011). For example, children generally prefer toys that are deemed typical for their own gender (e.g., vehicles for boys and dolls for girls; Davis & Hines, 2020; Todd et al., 2018). Moreover, children show a preference for same-sex peers and often adjust their play styles to match the sex of their play partner (e.g., Martin & Fabes, 2001; Trautner, 1995). Key (related) questions concern the origins of those gendered behaviours, and their reciprocal effects, especially how play interests and

Statement of contribution

What is known

- Gender plays an important role in children's play and social interactions.
- Sex-related hormones and gender cognitions contribute to independent gendered toy play.
- Compared to independent play, little is known about the origins of gendered peer play dynamics.

What the present study adds

- Novel methods map dyadic play in relation to prenatal androgen exposure in girls with CAH.
- Girls with and without CAH have play dynamics characterized by dyadic positive affect.
- Girls with CAH also seem to direct dyadic play through their vigour in ways similar to boys.
- Dyadic behavioural mapping enables joint study of individual characteristics and social context.

styles contribute to gendered playmate preferences and vice versa (Martin et al., 2013). In other words, do girls play with other girls because they identify as girls and prefer similar playmates, or because other girls play in ways they enjoy?

Most work on the origins of children's play has focused on gendered toy choices, and shows influences of both biology and social factors. Prenatal exposure to high levels of androgens increases interest and engagement with transportation and construction toys (reviewed in Berenbaum, 2018; Berenbaum & Beltz, 2021; Wallen, 2022). Social influences are apparent in children's preferences for toys labelled for their own sex over those labelled for the other sex (Davis & Hines, 2020; Leaper, 2015; Todd et al., 2018).

In contrast to toy play, other aspects of children's play – play style and playmate choice – reflect more than the individual; they are, by definition, an expression of social interactions of two (or more) children. Therefore, they likely depend on a complex and dynamic interplay of individual and group characteristics.

Such complexity is seen in children's peer preferences. Although preferences were long considered to reflect behavioural similarity alone, Martin et al. (2011) proposed an important additional role for children's gender cognitions (beliefs about boys and girls). Data confirm the importance for gendered peer interactions of both behavioural similarity and cognitions (Martin et al., 2011), including in girls with congenital adrenal hyperplasia (Berenbaum et al., 2018), as described below.

In the study reported here, we extended this perspective to gendered play that involves more than a single child. On average, boys' play involves physical activity, rough-and-tumble play and attempts to establish and maintain dominance, whereas girls' play is cooperative and involves quiet activities and verbal interactions that facilitate group harmony (Maccoby, 1986; Moller et al., 1992); positive emotionality, including kindness and consideration, is also more frequent in interactions among girls than among boys (Beltz et al., 2013; Chaplin & Aldao, 2013; Fabes & Eisenberg, 1998). These gender differences in play styles emerge early in childhood, are reinforced by peers, and are likely influenced by school practices that segregate children by sex (Leaper, 2015; Maccoby & Jacklin, 1987). Children likely socialize their own play styles, too, using gender schemas as motivation to behave in ways that are considered appropriate for their gender (and avoid behaving in ways that are considered inappropriate; Martin & Halverson, 1981). Similar sex-differentiated play styles are seen in other species; for example, from rodents to primates, rough-and-tumble play is much more common in juvenile males than in juvenile females, and is influenced by early hormones (reviewed in Wallen, 2005).

A unique opportunity to study influences on gendered play styles is provided by girls with congenital adrenal hyperplasia (CAH) who are exposed to high (sex-atypical) levels of androgens during prenatal development, but are reared and identify as girls (and have sex-typical postnatal androgens with treatment). They provide a natural experiment in two ways.

First, they permit an examination of the relative effects of prenatal androgens versus girl-typical rearing; this is the most common rationale for studying them. Indeed, studies of girls and women with CAH show that prenatal androgens influence a variety of gendered characteristics (for reviews, see Berenbaum, 2018; Berenbaum & Beltz, 2021; Blakemore et al., 2009). The largest effect is on gendered activities: girls and women with CAH show particular interest in and engagement with male-typed activities and careers in childhood, adolescence, and adulthood. Girls and/or women with CAH also differ – to a modest degree – from those without CAH in having higher levels of aggression (Berenbaum & Resnick, 1997; Pasterski et al., 2007), lower interest in babies (Leveroni & Berenbaum, 1998), greater preference for male-typed toys and playstyles (Berenbaum & Hines, 1992; Pasterski et al., 2011), increased likelihood of non-heterosexual orientation (Zucker et al., 1996) and enhanced spatial skills (Berenbaum et al., 2012; Hampson & Rovet, 2015; but see Collaer & Hines, 2020). In contrast, girls with CAH have gender-aligned cognitions and the vast majority of girls and women with CAH identify as women (e.g., Berenbaum et al., 2018; Endendijk et al., 2016; Engberg et al., 2020; Meyer-Bahlburg et al., 2006). Girls with CAH were not seen to be masculinized in their rough-and-tumble play during observed dyadic interaction (Hines & Kaufman, 1994), but they indicate larger preferences for rough-and-tumble play than unaffected girls in self-report (Pasterski et al., 2011). Boys and men with CAH, who are generally not exposed to elevated prenatal androgens compared to unaffected boys, are not significantly different from those without CAH on most characteristics that have been studied, including activities, aggression, interest in babies, identity and playmate preferences, although they do have lower spatial abilities (potentially owing to complications from the disease); cognitions and peer interactions have not been studied in boys with CAH (e.g., Berenbaum et al., 2012; Pasterski et al., 2011).

Second, the differential behavioural effects of androgens in girls with CAH provide an opportunity to examine associations among childhood gendered characteristics usually confounded in children without CAH. In particular, girls with CAH allow an examination of influences on gendered peer interactions of activity interests – which are more like those of boys than of unaffected girls – versus identity and cognitions about boys and girls – which are similar to those of unaffected girls. The value of this approach is seen in a study of gendered peer interactions in girls with CAH aged 10–13 years (Berenbaum et al., 2018). In daily telephone diaries, they reported little time spent with boys, and the amount of time spent with other girls was related to both activities and to gender identity and cognitions; prenatal androgens contributed to decreased time spent with other girls through an effect on increasing interest in boy-typical activities relative to girl-typical activities, but gender-aligned cognitions (e.g., self-perceptions and thoughts about gender roles) were still positively related to time spent with other girls.

Evidence from girls with CAH combines with recent advances in conceptualizing and analyzing dyadic data to enable the study of androgen influences on play styles in a more meaningful way than has been done to date, allowing a focus on the dynamics underlying same-sex peer interactions. Behavioural network mapping permits questions about play dynamics to be *uniquely* examined. Reflecting play sessions as a time series of various behaviours from each child, it identifies which behaviours influence other (self or peer) behaviours – and when. Previous work applying a behavioural mapping technique that reflects play dynamics to interactions during an unstructured play session among three or four unfamiliar peers revealed sex differences and dependencies (Beltz et al., 2013): girls displayed more positive affect than did boys, with affect depending on the prior (10 s before) affect of female partners; boys displayed more vigorous activity than did girls, with activity depending on the time-locked activity of their male partners.

Capitalizing on this method and findings of sex differences in both individual characteristics and partner dynamics during play, we conducted an exploratory study to see whether early androgens are associated with the nature of dyadic play. We examined levels of positive affect and vigour of activity as well as behavioural mapping indicators of child-directed play (i.e., centrality) and dyadic play dynamics. If prenatal androgens are primarily responsible for sex differences in play, then girls with CAH should show less positive affect and more vigorous activity (in levels and centrality indicators quantifying each behaviour's influence on the play interaction) than unaffected girls (reflecting levels similar to boys). Alternatively, if sex differences in play reflect a combination of gendered behaviour, rearing, identity, cognitions and peer interactions, then girls with CAH should show affect and vigour of activity, including levels and indicators of centrality and dyadic play dynamics, similar to that of unaffected girls. Boys with CAH were not expected to differ from boys without CAH.

METHOD

Participants

We report data on 40 pairs of children aged 3–8 years (M = 67.66 months, SD = 18.76). Each pair contained a focal child and a play partner. Focal children were 16 girls and six boys with CAH, and eight unaffected girls and 10 unaffected boys.[1] When focal children were scheduled for the test session, parents were asked to arrange for a playmate to participate in one part of the study. Focal children with CAH were recruited from paediatric endocrine clinics at university-affiliated hospitals. Parents provided written informed consent and children assented to participate. Unaffected children were siblings or first cousins of the children with CAH. The four groups did not differ significantly in age, according to a one-way analysis of variance (ANOVA), $F(3,34) = 1.26$, $p = .304$.[2] Participants were primarily White, non-Latine, and of middle socioeconomic status.

Many of the focal children have been studied on multiple occasions from childhood into young adulthood on a variety of gendered characteristics (summarized in Berenbaum, 2018; Berenbaum & Beltz, 2021). These participants represent a subset of children recruited for the initial phase of the study and the data reported here represent a reanalysis of a subset of published data (Hines & Kaufman, 1994). Of the 71 focal children who participated in the main study (27 girls and 11 boys with CAH, 15 unaffected girls, 18 unaffected boys), 58 had a playmate at the session. Children were further excluded for the current study because: (a) their playmates were opposite sex ($n = 6$), and thus not relevant to the focus on same-sex dyadic interaction, (b) their playmates were not unique, that is, they played with both the child with CAH and the unaffected sibling ($n = 9$), (c) their playmate was another focal child ($n = 2$) or (d) for data quality concerns (e.g., did not show behavioural variation during play; $n = 1$).

Measure and procedure

The play task was one of two administered during a single test session at home (for results on the other task measuring sex-typed toy play, see Berenbaum & Hines, 1992). The task (modified for dyads rather than trios from DiPietro, 1981) was originally chosen because it elicits sex-typed rough-and-tumble play, with behaviours similar to those influenced by early androgens in nonhuman animals. Children were brought into a play area containing a ball, a pillow, a small trampoline and, for the last half of the session, a 'bobo' (punching) doll; they were told to play however they wanted, and their play was videotaped. The sessions lasted 14 min.

Sessions were originally coded for rough-and-tumble play for 12 min of the session. Specific measures included playful physical assault, physical assault on object and wrestling, and a composite measure (for details, see Hines & Kaufman, 1994).

[1] In these data and as was typical for the time of data collection, sex and gender were not differentiated.

[2] Two participants were missing age reports, so group means were imputed.

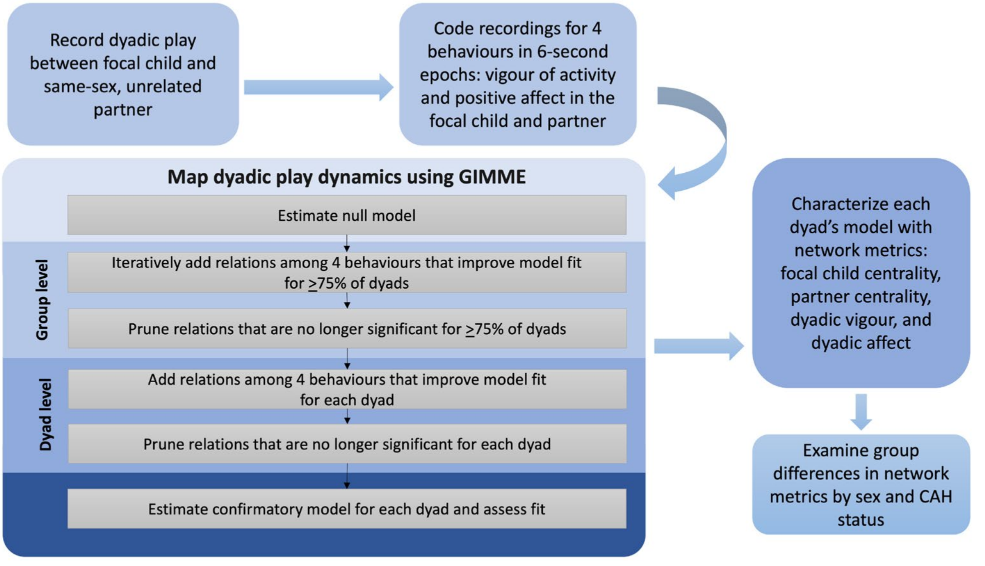

FIGURE 1 Data collection, processing, and analysis pipeline related to behavioural network mapping implemented via group iterative multiple model estimation (GIMME).

For the current study, videotapes were recoded for two gendered aspects of dyadic play: vigour of activity and positive affect. After establishing reliability on 10 pilot sessions, two coders independently rated recorded sessions. Specifically, the two behaviours were rated for each focal child and partner for each 6-s epoch across the approximately 14-min session, resulting in coded time series of length 140–151. Following past work (Beltz et al., 2013), positive affect was rated from 1 (no positive affect shown) to 5 (intense displays of positive affect), and vigour of activity was rated from 1 (no movement at all) to 5 (high intensity activity). Each dyad was rated by two independent coders, and their ratings were averaged for use in subsequent analyses. Interrater reliability (determined by intraclass correlation coefficients) ranged from .62 to .98, with an average of .86.

Analysis plan

To examine whether sex differences in past work were evident in this sample with this play task and coding scheme, the individual behaviour (i.e., average vigour of activity and positive affect across the 14-min play session) of focal unaffected girls and boys was compared using ANCOVAs, controlling for age, given the wide range in the sample (using SPSS version 29). Exploratory follow-up analyses were conducted to determine whether girls with CAH had play behaviours that differed from unaffected girls or boys.

As summarized in Figure 1, the behavioural ratings from each dyad were then submitted to a network mapping technique called group iterative multiple model estimation (GIMME; Gates & Molenaar, 2012) using version 0.7.15 of the *gimme* package in R version 4.2.3 (Lane & Gates, 2017). This data-driven technique combines a grouping algorithm that estimates directed relations among play behaviours that are common to all dyads (group-level relations) as well as relations among behaviours that are unique to dyads (dyad-level relations). Because it is based on unified structural equation modelling (uSEM; Gates et al., 2010), it also captures temporal dynamics by combining SEM with vector autoregression (VAR), thus estimating both contemporaneous (within the same epoch; in the SEM part of the model) and lagged (in the preceding 6-s epoch; in the VAR part of the model) relations among the behaviours of a focal child and their play partner.

The application of GIMME to developmental data has been described in detail elsewhere (Beltz & Gates, 2017; Chaku & Beltz, 2022). Briefly and as applied here, it built sparse networks unique to each dyad. It began by estimating autoregressive relations for each behaviour to account for temporal dependencies (e.g., the level of a child's vigour in the previous epoch is highly indicative of their level of vigour in the next epoch; Gates & Molenaar, 2012; Lane et al., 2019). Using Lagrange multiplier tests (i.e., modification indices; Sörbom, 1989) reflecting how much a network model would improve if a relation (contemporaneous or lagged) were estimated, it then determined whether any relations between the observed behaviours would significantly improve model fit for all dyads (indicated by a simulation-supported 75% of the sample; Gates & Molenaar, 2012). These group-level relations reflect homogeneity, and were iteratively estimated for all dyads if they existed. Next, GIMME again used modification indices to iteratively estimate relations (contemporaneous or lagged) that improved model fit for each dyad separately. These dyad-level relations reflect heterogeneity across dyads, and they were added to each model until models fit well according to three of four established cut-offs: root mean squared error of approximation (RMSEA) $\leq .05$, standardized root mean residual (SRMR) $\leq .05$, comparative fit index (CFI) $\geq .95$, and non-normed fit index (NNFI) $\geq .95$. All relations had estimated magnitudes and directions (i.e., positive or negative) that are unique to each dyad.

Following extrapolations from graph theory and past work (described in Beltz & Gates, 2017), the play of each dyad was characterized by four network metrics. *Focal child centrality*, reflecting the role of the focal child in the interaction, was indexed by the number of estimated relations (lagged or contemporaneous) that involved the vigour or affect of the participant in their dyad's network. *Partner centrality* was indexed by a parallel metric but concerned the number of play partner relations. *Dyadic vigour* was indexed by the number of estimated relations (lagged or contemporaneous) that connected the vigour of the focal child and partner. *Dyadic affect* was indexed by the number of estimated relations (lagged or contemporaneous) that connected the affect of the focal child and partner. All metrics were proportions, or the number of relevant relations divided by the total number of estimated network relations.

Lastly, each network metric (i.e., focal child centrality, partner centrality, dyadic vigour and dyadic affect) was examined for group differences in a 2 (sex) × 2 (CAH status) ANCOVA, controlling for age (using SPSS version 29). Exploratory follow-up analyses were conducted to determine whether significant effects were driven by specific aspects of the network (e.g., lagged vs. contemporaneous relations).

RESULTS

Analyses include sex comparisons on the focal child's levels of positive affect and vigour of activity, followed by behavioural mapping with GIMME and subsequent network metric abstraction and group comparisons. Regarding sex differences in play behaviour, ANCOVAs did not reveal a difference in vigour of activity, $F(1,15) = 0.83$, $p = .378$, partial $\eta^2 = 0.05$, with age a non-significant covariate, $F(1,15) < 0.001$, $p = .997$, partial $\eta^2 < 0.01$. They did, however, reveal the expected difference between unaffected girls (M = 3.15, SD = 0.48) and boys (M = 2.60, SD = 0.45) in positive affect, $F(1,15) = 8.36$, $p = .011$, partial $\eta^2 = 0.36$, with age a non-significant covariate, $F(1,15) = 2.12$, $p = .166$, partial $\eta^2 = 0.12$. Interestingly, follow-up analyses showed that girls with CAH (M = 2.61, SD = 0.69) displayed levels of positive affect nearly identical to that of unaffected boys, $F(1,23) = 0.10$, $p = .755$, partial $\eta^2 = 0.004$ and lower than unaffected girls, $F(1,21) = 4.52$, $p = .046$, partial $\eta^2 = 0.18$.

Regarding behavioural mapping, the estimated GIMME networks fit each dyad's data well, with average indices of RMSEA = .026, SRMR = .050, CFI = .987 and NNFI = .975. An example network of a dyad from each group is shown in Figure 2. Behaviours of the focal children are represented by black rectangles, and behaviours of their play partners are white rectangles. Each behaviour has an autoregressive relation, shown by the dashed lines emanating to and from the same rectangle; they are black because they are group-level relations estimated for every dyad in the sample. All dyad-level relations between behaviours are shown by grey lines. Lagged relations have dashed lines, whereas

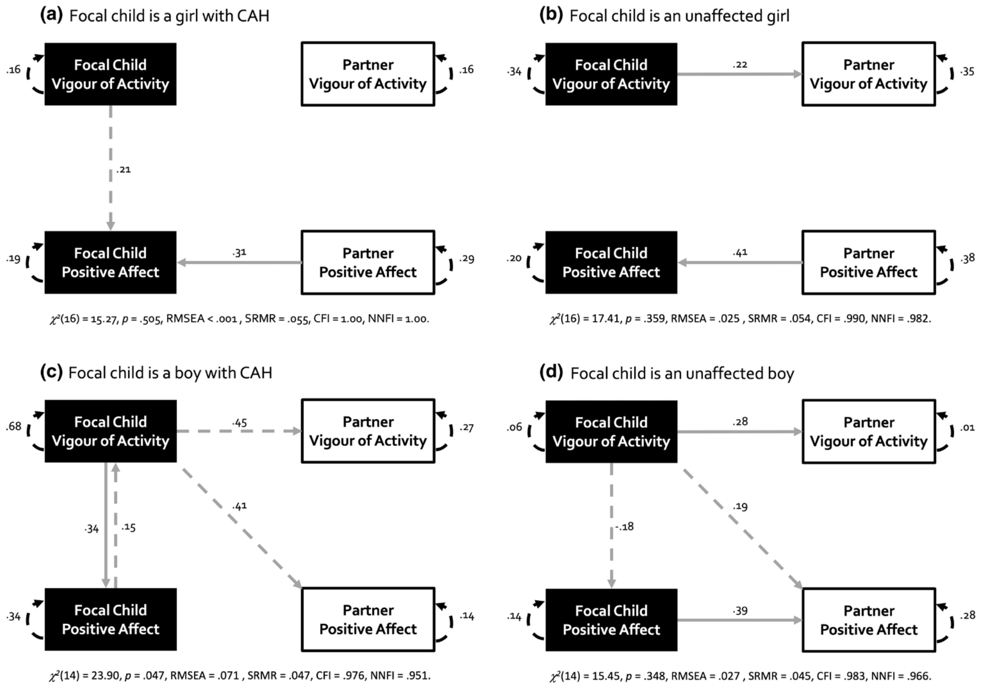

FIGURE 2 Example behavioural networks of play dyads estimated with group iterative multiple model estimation (GIMME), with model fit statistics.

contemporaneous relations have solid lines. All relations have beta weights associated with them, and the model for each dyad has a series of fit statistics.

Across all 40 dyads, there were no group-level relations (besides the four a priori specified autoregressives reflecting that a behaviour predicts itself over time), reflecting minimal homogeneity in play dynamics in the sample. Dyads had between one and eight estimated dyad-level relations ($M = 6.40$, $SD = 0.98$), reflecting heterogeneity. This is illustrated by the example dyads shown in Figure 2. In Figure 2a, the focal child is a girl with CAH. This dyad's behaviour is driven by the focal child's positive affect, which is explained by her partner's co-occurring affect, and from her own previous vigour of activity. Interestingly, the partner's vigour is not associated with any other behaviours (her own affect or the focal child's behaviour). Thus, this dyad's focal child centrality is four (with four relations involving a focal child behaviour), partner centrality is three (with three relations involving a partner behaviour), dyadic vigour is zero (as no relations involve both children's vigour of activity), and dyadic affect is one (with one relation involving both children's positive affect). Each of these metrics is divided by a network complexity of six (i.e., the number of estimated network relations) for use in subsequent analyses.

In Figure 2b, the focal child is a girl who does not have CAH. Play in this dyad is characterized by the synchrony of like behaviours: Both girls have time-locked relations for their vigour of activity and their positive affect; they are moving and emoting in sync with each other. The dyad's network metrics for focal child and partner centrality are each four, and dyadic vigour and affect are each one, with overall network complexity of six.

Figure 2c,d show dyads with focal boys who do and who do not have CAH, respectively. Play for the dyad in 2c is largely driven by the focal child's vigour of activity, which is concurrently related to his own positive affect and predicts the impending vigour and affect of his partner. A similar dynamic is seen for the dyad in 2d, with the focal child's vigour driving play, with indication of dyad-synchronized vigour and affect. For both dyads, network complexity is eight, focal child centrality is six, and dyadic

TABLE 1 Results of 2 (sex) × 2 (CAH status) factorial analyses of covariance on behavioural network metrics that characterize dyadic play dynamics.

	F	df	*p*-value	Partial η^2
Focal child centrality				
Age	**4.46**	**1,35**	**.042***	**0.11**
Sex	**4.15**	**1,35**	**.049***	**0.11**
Status	0.57	1,35	.455	0.02
Interaction	0.15	1,35	.700	<0.01
Play partner centrality				
Age	0.15	1,35	.703	<0.01
Sex	3.56	1,35	.068	0.09
Status	0.29	1,35	.591	0.01
Interaction	1.76	1,35	.194	0.05
Dyadic vigour				
Age	1.10	1,35	.302	0.03
Sex	0.01	1,35	.941	<0.01
Status	0.05	1,35	.820	<0.01
Interaction	0.004	1,35	.952	<0.01
Dyadic affect				
Age	2.54	1,35	.120	0.07
Sex	**5.04**	**1,35**	**.031***	**0.13**
Status	0.21	1,35	.647	0.01
Interaction	0.84	1,35	.365	0.02

Note: Descriptive statistics in Figure 3. Lines with significant effects were bolded for readability.

*Significant effects at $p \leq .05$.

vigour is one, but partner centrality is four and dyadic affect is zero for the dyad in Figure 2c, and partner centrality is five and dyadic affect is one for the dyad in Figure 2d.

Network metrics were submitted to two-way ANCOVAs. Results are listed in Table 1, with unadjusted group means and standard deviations displayed in Figure 3. For focal child centrality, there was a significant sex difference, but no effects of prenatal androgen exposure. Boys had greater centrality than girls, meaning that behavioural relations including the focal child characterized more of their dyad's play dynamics. Dyads including girls with CAH, however, had means that fell in between unaffected female dyads and male dyads. Follow-up analyses indicated that neither lagged nor contemporaneous relations were responsible for the sex effect ($p = .256$ and $p = .964$, respectively), but that relations with the focal child's vigour (not affect, $p = .836$) were driving the sex difference, $F(1,35) = 5.02$, $p = .031$, partial $\eta^2 = 0.13$. This is consistent with the example dyads shown in Figure 2c,d in which the focal boys seemed to be directing dyadic play through their vigour of activity. For partner centrality, there were no significant effects. The effect size, however, indicated a potentially meaningful sex difference, with girls having greater partner centrality than boys regardless of CAH status.

For dyadic play metrics, there was a significant sex difference for affect. Compared to boys, girls had more relations between the positive affect of partners (regardless of focal child CAH status). In fact, 95.83% of female dyads had at least one relation between focal child and partner affect, but only 62.50% of male dyads did. Contemporaneous (not lagged, $p = .857$) relations seemed to be driving this effect, $F(1,35) = 6.11$, $p = .018$, partial $\eta^2 = 0.15$. These reflect the time-locked affect relations seen for the dyads in Figure 2a,b,d. There were no significant effects for dyadic vigour of activity.

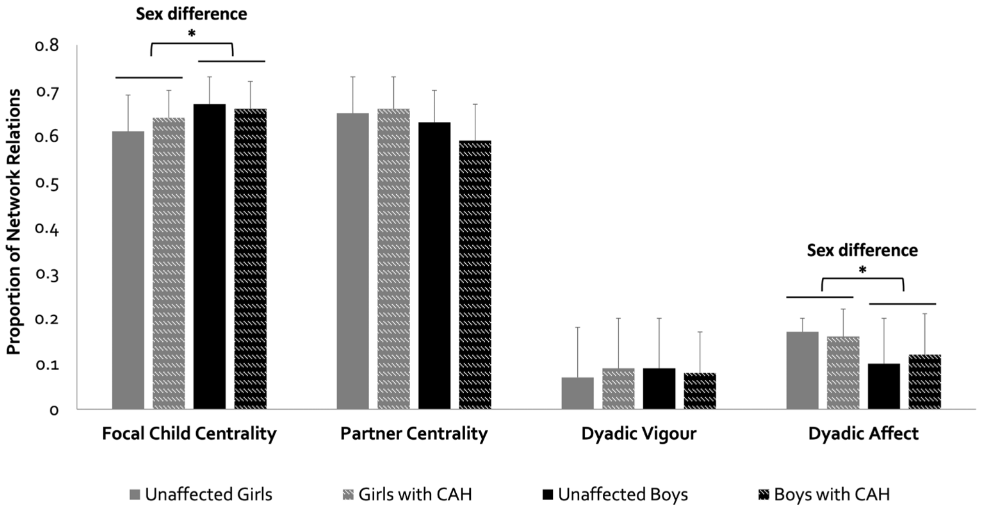

FIGURE 3 Descriptive statistics for group differences in behavioural network metrics that characterize dyadic play dynamics. Columns show group means, with standard deviation error bars. $^*p \leq .05$ in factorial analysis of covariance, controlling for age; see Table 1.

DISCUSSION

This study of dyadic play in children with and without CAH provides a unique opportunity to understand key developmental questions: how prenatal androgen affects behaviour, how social interactions result from the gendered characteristics of individuals, and their influences on each other. Results from behavioural mapping of dyadic play highlight that girls with CAH have positive affect that is in sync with their play partners in ways and to degrees similar to unaffected girls (and to a greater extent than boys with and without CAH). Behavioural mapping was critical to this insight, because it permitted investigations that went beyond individual levels to play dynamics. In fact, behavioural networks revealed sex-related effects in play dynamics that were different from those suggested by individual means of positive affect, with girls with CAH showing low levels of positive affect, similar to that of unaffected boys.

Thus, findings require consideration of the level of analysis. Girls with CAH showed less positive affect than girls without CAH in follow-up individual analyses, but in dyadic interactions, they synced their positive affect with play partners in ways similar to girls without CAH. Thus, androgens seem to influence aspects of positive affect on an individual level, but those influences are modulated by the social context related to gendered status and identity at the dyad level. This suggests that hypotheses about gender development are not simply alternatives, and that behavioural mapping techniques are able to reveal the ways in which individual characteristics manifest and are modified in social interactions.

There was also some suggestion that girls with CAH were in between boys and girls without CAH in directing dyadic play, as reflected in the focal child centrality metric. The sex difference in focal child centrality (regardless of CAH status) revealed greater centrality for boys than girls, but an examination of the means revealed that girls with CAH had intermediate centrality. Larger samples (with more statistical power) or different play scenarios (e.g., with same-sex groups instead of dyads; Fabes et al., 2003) could realize this potential effect in future work. Indeed, this is a novel aspect of play revealed through behavioural mapping that might be incorporated into studies of gendered play styles.

Despite the focus on groups with girls and boys with and without CAH in this study, it is important to emphasize heterogeneity. The behavioural mapping approach revealed the unique play dynamics for each dyad (with examples shown in Figure 2) that may or may not reflect their group's 'average' pattern reflected by the ANCOVAs. For instance, the play dynamics represented by the dyad in Figure 2b, with time-locked vigour and affect, was displayed by 3 other dyads in the sample, one including a girl with CAH, one including a boy with CAH, and one including a boy without CAH.

Methodological considerations

Results need to be considered in light of methodological strengths and limitations. The uniqueness of the sample creates both opportunities and constraints.

Limitations common to studies of girls with CAH

CAH is not a perfect experiment, and alternative explanations for behavioural masculinization have been proposed, particularly parents' response to girls' virilized genitalia (resulting from high prenatal androgens) and other aspects of the disease or treatment. As discussed elsewhere (Berenbaum & Beltz, 2021), neither parent behaviour nor other characteristics of CAH can fully account for most behavioural masculinization (e.g., Pasterski et al., 2005; Servin et al., 2003), and findings in individuals with other differences in sex development (DSD) support findings in CAH. Crucially, specificity in behavioural findings – girls and women with CAH differ from those without CAH on some behaviours and not others – argue against alternative explanations.

Considerations specific to this study

The main limitations concern the relatively small sample and the reanalysis of data collected some time ago for another purpose. There is no evidence for secular changes in sex differences in play style or behaviour in girls with CAH (Kung et al., 2024). Although statistical power for the behavioural networks is determined by time series length, which was sufficient at 140 or more observations per dyad (Beltz & Gates, 2017; Lane et al., 2019), there was only power to detect large effects in factorial ANCOVAs. This may have prevented the detection of interaction effects for girls with CAH in focal child centrality. Regardless, results are considered preliminary and require replication. The novelty of the dyadic play design and behavioural network mapping approach nonetheless offer empirical intimations that can now be examined in future confirmatory work.

Furthermore, this study is unique given the rarity of CAH, and the challenge of collecting observational data of social play in any selected sample. In fact, most behavioural studies of people with CAH and other DSD use questionnaires and paper-and-pencil or computerized tasks, focusing on personal characteristics; data on social interactions are rare, generally based on reports from the person with CAH or a parent, usually with questionnaires, and, in only one study, from daily diaries (Berenbaum et al., 2018). No other study has included analyses of dyadic features of interactions.

Another consideration concerns the play partner. Parents were asked to arrange for a play partner, and it is not known what factors went into their choice; for example, parents may have chosen their daughter's best friend, a daughter of their own friends, a relative or a neighbour. The small number of girls who brought a male playmate precludes a meaningful analysis of effects of playmate sex. It would be very interesting to use this design and vary the playmate to reflect the focal child's choice versus a stranger.

Relatedly, studying dyads in a setting likely to elicit rough-and-tumble play might have limited the ability to detect the sex differences typically seen in gendered play. The high vigour characteristic of boys is most prominently seen in large groups, as shown in previous work with behaviour mapping (Beltz et al., 2013), and despite compelling evidence that boys are more likely to engage in rough-and-tumble play than girls, they seem to display similar levels of vigour during that play (Fabes et al., 2003; Pellegrini, 2002).

Considerations linked to behavioural mapping

Time is critical in mapping play dynamics, and it has implications for directionality as well as inferences. Although there is temporal evidence for directionality in the lagged relations, we used a GIMME approach that is not best suited for parsing the directionality of contemporaneous relations (see Beltz & Molenaar, 2016). For this reason, we did not interpret relation directionality (nor consider this in the network metrics). Also, it is unclear whether the 6-s epochs used in coding were ideal for reflecting the play dynamics of the task. Clearly, shorter or longer epochs would have the potential to influence the estimation of lagged versus contemporaneous relations, as contemporaneous is defined as behavioural relations occurring within an epoch (see Beltz & Gates, 2017).

Nevertheless, the power of the behavioural mapping technique is clear. It enables quantitative analysis of integrated perspectives on social interaction, evaluating both the role of a child's individual characteristics and the role of social context at the level of specific dyads (i.e., without averaging across heterogeneous play groups). Furthermore, the measure of focal child centrality provides an opportunity to consider a new index of the child's role in social interactions: as a director of play. This is a common conceptualization in graph theory, but novel in its application to play behaviour.

The study in broader context of gender development

Studies of girls with CAH have generally focused on their role in confirming evidence from other species showing the behavioural importance of hormone exposure during sensitive periods of development. This study demonstrates the additional value of girls with CAH for understanding psychological processes, particularly by considering how hormonally influenced behaviours combine with other factors in affecting complex behavioural outcomes. Further, the use of behavioural mapping techniques provides information beyond typical indices such as means of individuals. Our findings show the complexity of potential androgen effects: They may affect some play behaviours, but give way to gendered rearing, identity, and cognitions in the context of dyadic interactions.

In this context, it is interesting to compare play in children and other species. Our data suggest that early hormones influence some aspects of dyadic play in people, as they do in other species, but perhaps to a lesser extent. It is possible that species differences reflect the timing or amount of hormone exposure. Perhaps more important, however, are effects on human dyadic play of characteristics not found in other species, particularly gender identity and gender cognitions.

Our findings also support other work on gender development. First, they are consistent with indications that gender socialization occurs, at least in part, through children's internal representations of their world, and not exclusively through direct socialization (e.g., modelling, parental treatment; e.g., Hines et al., 2016; reviewed in Leaper, 2015). The limited studies of direct socialization of girls with CAH suggest that they are not generally treated in a more 'male-typical' way than girls without CAH (Pasterski et al., 2005; Servin et al., 2003), although some parent reports are discrepant (e.g., Wong et al., 2013). Regardless, girls with CAH clearly internalize the gendered nature of their environments, as shown in their gender-typical attitudes and beliefs (Endendijk et al., 2016). Second, our findings emphasize the importance of studying children in context, with analyses that allow parsing of the nature of both individual and dyadic behaviours.

In conclusion, this exploratory study illustrates an approach to understanding gender development that allows for consideration of both biological and social influences. Studies of girls with CAH tell us not just about hormonal influences on behaviour; they provide an opportunity to examine the nature and causes of gender diversity generally.

AUTHOR CONTRIBUTIONS

Adriene M. Beltz: Conceptualization; data curation; formal analysis; methodology; software; resources; supervision; visualization; writing – original draft; writing – review and editing. **Christel M.**

Portengen: Writing – review and editing; visualization. **Sheri A. Berenbaum:** Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data unfortunately cannot be shared because the participants are identifiable, and permission was not provided to share such data.

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