Early Human Development 195 (2024) 106055

Contents lists available at ScienceDirect

Early Human Development

journal homepage: www.elsevier.com/locate/earlhumdev

# Investigating the effects of prenatal testosterone exposure (via 2D:4D) and socio-relational factors on 3–6-year-old preschoolers' prosocial choices

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ARTICLE INFO

*Keywords:*
Prosociality
Prosocial choice task
2D:4D
Prestige
Dominance
Friendship

ABSTRACT

*Background and aims:* Prosocial behavior such as helping and sharing develops early in childhood. Yet very few studies have investigated physiological and relational factors shaping prosociality among children. Here, we systematically examined the role of prenatal androgen exposure alongside prestige, dominance, and friendship in 3–6-year-old preschoolers' prosocial sharing with familiar peers.
*Methods:* We tested a sample of 65 children, predominately of European descent. We used a cost-free direct-interaction prosocial choice task to assess children's prosocial tendencies. Second-to-fourth digit ratio (2D:4D) was used as a retrospective biomarker for prenatal androgen exposure. Prestige was measured through behavioral observations of interaction partners and visual regard, dominance through teacher questionnaires, and friendship via peer preference assessments.
*Results:* We found that children acted prosocially when tested with a familiar peer. Children with lower 2D:4D (higher prenatal androgen exposure) behaved more prosocially. Further, there were marginal associations between the donors' prosocial tendencies and their visual regard as a proxy of their prestige (positive effect) and their teacher-rated dominance relative to the recipient (negative effect). Neither age, sex, nor friendship influenced prosocial choices.
*Conclusions:* Prenatal androgen exposure, approximated via 2D:4D, was associated with prosocial behavior. In contrast to previous research in older children, higher exposure was related to stronger prosocial tendencies, which corresponds to earlier findings on fairness in adults. Our findings point towards a potential role of sex steroids in the early development of children's social behavior, but they have to be interpreted with caution due to the small sample size of the current study. Nevertheless, they underscore the importance of integrating biological and psychological perspectives, while also highlighting the significance of studying the development of prosocial behavior within peer groups.

## 1. Introduction

Human propensity for prosocial behavior, the voluntary act of helping and supporting others, begins early in life. By age two, children help in simple tasks [1], and by age three, they begin sharing resources, influenced by experience and social norms (e.g., [2]). Prosocial tendencies vary among individuals, with prenatal androgen exposure affecting early development [3,4] (but see [5]). Additionally, social factors, like prestige, dominance, and friendship shape children's prosocial decisions (prestige: [6]; dominance: [7]; friendship: [8]). The scarcity of studies investigating prosociality as a function of both children's physiological traits and social relationships with familiar peers motivated this study.

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https://doi.org/10.1016/j.earlhumdev.2024.106055
Received 15 April 2024; Received in revised form 25 May 2024; Accepted 30 May 2024
Available online 6 June 2024

Exposure to androgen in utero is linked to gender-typed appearance and behaviors, suggesting a general masculinization effect, such as increased aggression and dominance [9–11]. The most direct evidence comes from studies measuring androgen exposure via amniotic fluid [11]. Additionally, prenatal androgen exposure can be approximated later in life using the second-to-fourth digit length ratio (2D:4D) [12,13] (for molecular pathways in a mouse model, see [14]), where higher prenatal androgen exposure corresponds to lower 2D:4D. Besides 2D:4D, the difference between 2D:4D of the right and left hand (Dr−l) has been suggested as a correlate of prenatal androgen exposure, with low Dr−l indicating high exposure [15,16]. Therefore, 2D:4D offers a non-invasive method for studying early androgen effects in prepubertal children.

Pre- and elementary school children with high 2D:4D (i.e., lower prenatal androgen exposure) are perceived as more prosocial by parents and/or teachers [3,4]. Corroborating this evidence, 6–9-year-olds with higher 2D:4D were found to make more prosocial choices as compared to peers with lower 2D:4D, indicating a competitive orientation of children with higher prenatal androgen exposure [17]. The more abundant adult literature suggests that the relationship between 2D:4D and prosocial behavior might be context-dependent [18]. While one study also found a positive correlation between 2D:4D and prosocial offers in a resource allocation experiment [19], Millet and Dewitte [20] showed that adults with lower 2D:4D were more likely to give a fair share and less likely to give either more (prosocial) or less (selfish) in a public goods game. Interestingly, this relationship was inverted after exposure to aggression cues (e.g., aggressive videos). In this situation, participants with higher 2D:4D donated more to an anonymous recipient [21], paralleling the findings in 6–9-year-old children [17]. Millett and Dewitte [21] argued that individuals with lower 2D:4D tend towards normative and fair behavior, but may exhibit more asocial choices in status-relevant contexts.

Social status is based on prestige (respect and popularity; [22]) and/or dominance (coercion; [23]), and children differentiate between these two aspects of status by 21 months [24]. Children's prestige can be gauged by their popularity, such as the number of interaction partners or the visual attention they receive from peers [25]. Preschool children expect an individual with high prestige to contribute more towards a joint goal and to withdraw only an equal share from common resources [26]. In line with these expectations, 8–12-year-old children with high levels of visual regard from their peers were found to be particularly prosocial by donating resources and intervening in fights [6]. Children's dominance is typically operationalized as the ability to prevail in resource conflicts. It can be measured via questionnaires administered to teachers who had the chance to observe the children's interactions over extended periods [27] or staged dyadic resource competition tasks [28]. Preschool children anticipate that dominant individuals would not assist others and perceive unhelpful individuals as being in charge [29]. In fact, dominant preschoolers donated fewer valuable items to an anonymous recipient [7] and were more likely to acquire higher payoffs than their partners in cooperative tasks [28]. Gender-specific associations between dominance and prestige in children are notable, with dominant girls being liked less, whereas dominant boys are liked more by their peers (e.g., [30]). Thus, separately analyzing prestige and dominance effects on children's prosocial behavior is crucial, as well as considering gender interactions.

Friendships are also important social relationships between preschoolers. Children expect more kindness among friends than others and are more inclined to share with friends over disliked peers [8,31], particularly among girls [32]. However, Berndt [33] found that while children, especially girls, claimed they would share more with friends than acquaintances, sharing behavior did not differ in direct interactions (see also [17]). These results stress the importance of observing children's direct interactions to fully understand their prosocial decision-making processes, where status-related factors could outweigh friendships among young peers.

The aim of the current study was to investigate 3–6-year-old children's prosocial tendencies towards a familiar peer in a cost-free direct-interaction prosocial choice task [17]. We predicted that preschool children would demonstrate prosocial behavior by choosing the prosocial option (i.e., one reward for both donor and recipient) more often with a recipient present. We further examined whether prenatal androgen exposure (via 2D:4D) as well as prestige, dominance and friendship were related to children's prosocial behavior. Additionally, we tested for effects of donor sex, age, and recipient request. We expected that a lower prenatal testosterone exposure (higher 2D:4D) would be associated with relatively more prosocial choices [17]. Children with high prestige were hypothesized to be more prosocial [6]. We anticipated that donors with higher dominance than the recipients would behave less prosocially [7], and that this effect would be more pronounced in boys than in girls [30]. Finally, we expected that children would share more when they were paired with a friend [8], and that this effect would show an interaction with sex (i.e., more pronounced in girls; [32]).

## 2. Material and methods

### 2.1. Participants

Participants were recruited from five private, bilingual (German, English) childcare facilities in Vienna, Austria. The total sample consisted of 65 children (36 females) between 3 and 6 years of age ($M \pm SD$ = 4.88 years±11 months, range = 2.91–6.61 years). The sample was relatively evenly split between younger (3–4 years, $n = 35$) and older children (5–6 years; $n = 30$). The female participants ($M \pm SD = 4.91$ years±12 months) did not differ in age from the male participants ($M \pm SD = 4.84$ years±10 months; $t = 0.290$, $df = 61.96$, $p = 0.773$, $d = 0.07$). The majority of the participants were of European descent (Western European: $n = 40$; Eastern European: $n = 3$; Northern European: $n = 1$; Mixed European: $n = 10$; Mixed Western European/Australian: $n = 2$; Mixed Western European/Latin American: $n = 2$; Mixed Western European/North American: $n = 1$; Middle Eastern: $n = 1$; Undisclosed ethnicity: $n = 5$). All children were White.

Prior to the study, informed consent was obtained from all participants' parents or legal guardians and the children's participation in the study was voluntary. All procedures were carried out in accordance with the Declaration of Helsinki and had been approved by the institutional ethics committee (Ref. No. 00103; 05.02.2015) and the respective childcare institutions. Data was collected from October 2016 to June 2017.

### 2.2. Prosocial choice task

The experimental apparatus (see Supplementary material, Supplementary Fig. S1) and procedure for the prosocial choice task were the same as in Horn et al. [17]. The apparatus consisted of two wooden boxes (84 × 20 cm each) fixed on a wooden plate (100 × 80 cm) and was placed on a table during testing. The two boxes were closed seamlessly on top with transparent Plexiglas lids, so that children could look inside the boxes, but not open them. On the donor's side were two coin receptacles, one in front of each box. When inserting a coin into the coin receptacle, the Plexi lid of the corresponding box lifted so that the children could get access to the contents inside the box. The mechanism was operated by the experimenter by means of a hidden remote control. The experimenter always placed 2 stickers in one box (1/1 option) and 1 sticker in the other box (1/0 option) in a conspicuous way, so that the sticker distribution was obvious. Each time she started with placing the rewards in the right box. Which box contained which option was counterbalanced across trials. Testing took place outside the preschool group's regular room in a quiet location (e.g., gym room).

There was a warm-up and a test phase. During the warm-up phase, children were told that they could explore how the apparatus worked and the boxes could be opened with a coin provided to them in every trial. In the warm-up, no other child was present. There was no barrier between the two sides and the donor could retrieve stickers from both the donor and the recipient side of the chosen box. The donor could thus maximize their payoff by choosing the 1/1 option. Due to the younger age of the participants compared to Horn et al. [17], we chose a less stringent criterion for proceeding to the test phase. If children chose the 1/1 option in every trial of the first 4 trials, they proceeded to the test phase ($n = 4$). If not, they received another block of 4 trials and proceeded to the test phase when the 1/1 option was chosen in at least 5 out of 8 trials ($n = 39$). Twenty-two children failed this criterion and did not participate in the test phase. To check for the robustness of our findings with a stricter criterion for task comprehension, we also calculated our main analysis with children who chose the 1/1 option significantly above chance during the warm-up ($n = 22$). There was no age difference between participants who did or did not pass the original criterion, but children that passed the stricter criterion were significantly older than children that failed it ($N = 65$; original criterion: $t = -1.548$, $df = 62$, $p = 0.127$; stricter criterion: $t = -3.851$, $df = 62$, $p < 0.001$).

Before the test phase, the experimenter put up a physical barrier (e.g., chairs or tables), which prevented the donor from retrieving the stickers from the recipient side. She told the participants that they would now play the game a few more times, with and without another child present, but gave as few instructions as possible. Each donor was then tested in two conditions. In the prosocial test, a recipient child was present on the recipient side and could retrieve a sticker, if the donor chose the 1/1 option. In the non-social control there was no recipient present, but the donor could not obtain the sticker on the recipient's side (i.e., the sticker was returned to the experimenter's stash). The sequence of the two conditions was counterbalanced across children. In each condition, the donor received 10 consecutive trials. Some children played the roles of both donor and recipient in separate sessions. Participants always played the role of donor first. Most children were tested with a same-sex partner ($n = 38$), while five children were tested with an opposite-sex partner (3 females).

### 2.3. 2D:4D measurements

The palmar surface of each hand was scanned using a Canon LIDE 110 flatbed scanner with a manually inserted calibration scale. Digital hand scans were obtained from 59 of the participating children (left hand scan missing: $n = 3$). None of the children had finger injuries or other conditions that could affect measurement validity. We used the ruler tool in the program Adobe Photoshop to measure the lengths of the index finger (2D) and the ring finger (4D) twice from the ventral-most proximal crease to the tip of the gently stretched finger from both right and left hand [34]. If the difference between the first and second measurement was larger than 0.5 mm, a third measurement was performed to retain the two closer scores (cf. [17]). The length of the index finger was divided by the length of the ring finger to obtain the 2D:4D measure. The 2D:4D measures between the first and second measurements were significantly correlated ($\rho = 0.989$, $p < 0.001$), and a paired $t$-test confirmed no significant difference between the two measurements ($t = 0.743$, $p = 0.461$; average difference 0.0006, $SD = 0.00571$). Thus, further analyses were conducted based on the mean values of the two measurements. Measurement reliability was ensured as part of a larger project, yielding $\rho = 0.979$ ($p < 0.001$) and no significant difference between the current rater and a second independent rater (Pillai trace = 0.006, $F = 1.514$, $df = (1, 254)$, $p = 0.220$). The majority (98 %) of the length measurements showed a difference of $\leq$0.5 mm.

The 2D:4D measures of the right and the left hand were significantly correlated ($r = 0.652$, $p < 0.001$). Dr–l measures were obtained by subtracting left-hand 2D:4D from right-hand 2D:4D. Because the right hand has been argued to show a stronger association with prenatal androgens than the left hand [35], we used the right-hand 2D:4D measure as a predictor in the subsequent statistical model. As a robustness test, we additionally ran the main model with left-hand 2D:4D instead of right-hand 2D:4D. Results of this model can be found in the supplementary material (Supplementary Table S1).

### 2.4. Observational assessment of interaction partners and visual regard

The children were observed in their classrooms during two unstructured play periods on two separate days by a team of graduate students. Live observations were conducted from unobtrusive vantage points and children's reactivity was minimal, as they were accustomed to the presence of language assistants and teaching trainees in their classrooms. We used instantaneous sampling (interval = 15 s; sequence of children predetermined randomly and fixed within each group). One focal child was observed at each sampling point and we recorded two variables: number of interaction partners (i.e., other children at arm's length) and visual regard (i.e., the number of children attending to the focal child; cf. [17]). In total, we attempted to observe each child 12 times, 6 times per session. Some children were only present during one observation session or were not present at single sample points (obtained sample points across all children: $Mdn = 12$, range = 5–12). Therefore, we calculated the average number of interaction partners and visual regard per sampling point for further analyses. In three childcare facilities, multiple raters observed the children in parallel. Average inter-rater reliability was good across childcare facilities and observation days for interaction partners ($\kappa = 0.849$) and visual regard ($\kappa = 0.761$).

### 2.5. Dominance questionnaire

An online teacher questionnaire was created with SoSci Survey [36]. Two classroom teachers rated each child's social dominance on a continuous, graphic rating scale ranging from "strongly disagree" (1) to "strongly agree" (101) for four items: assertive, dominates classmates, tells others what to do, stands up for self [27]. The numerical scale was hidden from the participants. Internal consistency of the four items was excellent ($\alpha = 0.934$), therefore we calculated a mean dominance score for each child per classroom teacher. The dominance scores of the two teachers within each classroom showed a significant correlation ($r = 0.388$, $p = 0.002$), which fell within the range of cross-informant correlations of ratings of similarly aged children's social behaviors reported in meta-analytic studies (e.g., [37]). Thus, we used the mean dominance score across both teachers in the statistical model.

### 2.6. Friendship assessment

We used the Peer Preference Assessment [32] to measure friendships between children within each group. Each participant was tested in a separate room, with a table with three cartoon faces displaying a happy, sad, and neutral expression, respectively. We used photographs of all other participating children and first asked the participants to name all the depicted children to ensure recognition. Then we asked children to place each photograph into one of three categories exemplified by the three cartoon faces: (a) happy – like to play with, (b) sad – don't like to play with, (c) neutral – just okay/don't really care. We used category (a) as a proxy for friendship and category (b) as a proxy of an absence of friendship. This method avoids encouraging children to say that they have many friends and has been used to reliably detect friendships [30]. Half of the children were paired with a friend ($n = 21$) and half with a non-friend ($n = 22$) in the prosocial choice task.

### 2.7. Data analyses

All hypotheses and predictions were formulated before data collection started, but they were not preregistered online. No additional data were collected after the analyses. Statistical analyses were carried out in R version 3.6.0 [38]. $P$-values $\leq$0.05 were considered statistically significant and $p$-values <0.1 are reported as non-significant trends.

In a first step, we tested for sex differences (Welch's *t*-tests) in all independent variables and correlations between the predictor variables of the subsequent statistical model (Pearson's correlations). We then analyzed the behavior of the children who passed the original criterion of the warm-up and participated in the test phase ($n = 43$). We tested whether the number of 1/1 choices differed from chance level and differed between the two conditions (prosocial test, non-social control) for the total sample, as well as separately for younger (3–4 years) and older children (5–6 years; Wilcoxon signed-rank tests). We further investigated whether recipient requests were more likely to occur in friend or non-friend dyads and whether a recipient request changed the probability of the donor choosing the 1/1 option on a trial-by-trial basis (Fisher's exact tests).

To analyze children's prosocial tendency with regard to physiological and relational characteristics, we controlled for the donor's general preference for choosing the 1/1 option, irrespective of the presence of a partner. To calculate the prosocial tendency (Pt), we subtracted the number of 1/1 choices in the non-social control condition from the number of 1/1 choices in the test. We then calculated a corrected prosocial tendency (Pt') to correct for the fact that the maximum theoretical value that a child could attain depended on the number of 1/1 choices in the control condition. We used the following two formulas (cf. [39]):

$$\text{If } Pt > 0; Pt' = Pt/(\text{proportion of } 1/0 \text{ choices in the non–social control})$$

$$\text{If } Pt < 0; Pt' = Pt/(\text{proportion of } 1/1 \text{ choices in the non–social control})$$

Thus, the corrected prosocial tendency score could range between −10 and 10. A positive prosocial tendency score shows prosocial behavior, whereas a negative score shows selfish behavior. Further, since a donor's dominance had to be regarded in relation to the recipient's dominance, we calculated the donor's relative dominance by subtracting the recipient's dominance rating from the donor's dominance rating. A positive relative dominance score shows that the donor is dominant over the recipient, whereas a negative score shows that the recipient is dominant over the donor.

We calculated a general linear model with *prosocial tendencies* as the dependent variable. Children's *right 2D:4D, number of interaction partners*, *visual regard*, *relative dominance* and the interaction between relative dominance and sex, *friendship* and the interaction between friendship and sex, and the control variables *age*, *number of trials with recipient requests*, and *sex* were included as predictors. We excluded three children from whom we had not obtained all predictor measurements from the model calculations, resulting in a final sample size of $n = 40$. Adequacy of the model was confirmed by assessing normal distribution of residuals with Shapiro-Wilk tests and by visually inspecting Q-Q plots. To check the robustness of our findings regarding task comprehension, we also ran this analysis including only the children that chose the 1/1 option significantly above chance level in the warm-up phase and had no missing predictor values ($n = 21$). Due to the small size of this subsample, we could not run the full model, but included only the predictors that were (near) significant in the original model (i.e., *right 2D:4D*, *visual regard*, *relative dominance* and the interaction between relative dominance and sex, *number of trials with recipient requests*).

## 3. Results

Donor children chose the 1/1 option significantly above chance level only in the test ($n = 43$, $Mdn_{1/1} = 8$, 3 ties, $T+ = 726.5$, $p < 0.001$), but not in the non-social control ($Mdn_{1/1} = 5$, 5 ties, $T+ = 334.0$, $p = 0.598$). They chose the 1/1 option significantly more often in the test than in the control condition (overall: 4 ties, $T+ = 631$, $p < 0.001$; 3–4 years: $n = 21$, 2 ties, $T+ = 154$, $p = 0.018$; 5–6 years: $n = 22$, 2 ties, $T+ = 167$, $p =$

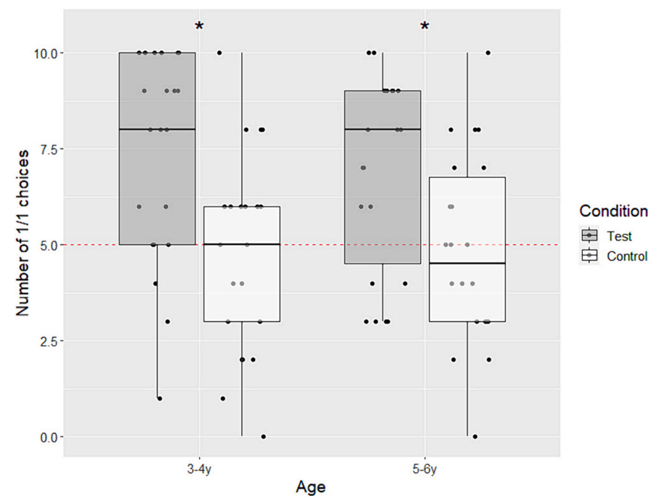


**Fig. 1.** Number of 1/1 choices in the prosocial test and the non-social control in younger (3–4y) and older children (5–6y). The box plots represent medians (center horizontal lines), inter-quartile ranges (boxes), as well as minima and maxima (whiskers). The dashed line indicates chance level. *$p \leq 0.05$.

**Table 1**
Descriptive statistics of the independent variables overall and per sex, as well as the results of the statistical test for sex differences.

| Variable | *M* ± *SD* | *t* | *df* | *p* | *d* |
|---|---|---|---|---|---|
| Right 2D:4D | 0.94 ± 0.038 (*N* = 59) | | | | |
| Females | 0.94 ± 0.035 (*n* = 33) | −0.094 | 48.80 | 0.926 | −0.03 |
| Males | 0.94 ± 0.042 (*n* = 26) | | | | |
| Left 2D:4D | 0.94 ± 0.038 (*N* = 56) | | | | |
| Females | 0.94 ± 0.029 (*n* = 30) | −0.192 | 40.53 | 0.849 | −0.05 |
| Males | 0.94 ± 0.046 (*n* = 26) | | | | |
| Dr–l | −0.001 ± 0.031 (*N* = 56) | | | | |
| Females | −0.001 ± 0.028 (*n* = 30) | −0.144 | 48.23 | 0.886 | −0.04 |
| Males | −0.001 ± 0.035 (*n* = 26) | | | | |
| Interaction partners | 2.30 ± 0.955 (*N* = 60) | | | | |
| Females | 2.29 ± 1.053 (*n* = 33) | −0.107 | 57.97 | 0.915 | −0.03 |
| Males | 2.32 ± 0.839 (*n* = 27) | | | | |
| Visual regard | 0.43 ± 0.339 (*N* = 60) | | | | |
| Females | 0.41 ± 0.293 (*n* = 33) | −0.467 | 47.04 | 0.643 | −0.12 |
| Males | 0.45 ± 0.394 (*n* = 27) | | | | |
| Dominance rating | 47.82 ± 23.990 (*N* = 64) | | | | |
| Females | 50.84 ± 19.559 (*n* = 36) | 1.092 | 45.54 | 0.280 | 0.29 |
| Males | 43.94 ± 28.622 (*n* = 28) | | | | |
| Relative dominance[a] | 0.61 ± 32.110 (*N* = 43) | | | | |
| Females | −0.40 ± 25.200 (*n* = 26) | −0.229 | 23.82 | 0.820 | −0.08 |
| Males | 2.15 ± 41.354 (*n* = 17) | | | | |

[a] Relative dominance scores are only available for children who participated in the prosocial choice task.

**Table 2**
Bivariate correlations of the predictor variables with each other and with age. Correlations with *p*-values ≤0.05 are highlighted in bold.

| | Age | 1. | 2. | 3. |
|---|---|---|---|---|
| 1. Interaction partners | −0.16 ($n$ = 59) | – | | |
| 2. Visual regard | **0.26[*] ($n$ = 59)** | 0.15 ($n$ = 60) | – | |
| 3. Dominance rating | 0.22[§] ($n$ = 63) | −0.07 ($n$ = 60) | 0.09 ($n$ = 60) | – |
| 4. Right 2D:4D | 0.02 ($n$ = 59) | 0.10 ($n$ = 57) | 0.14 ($n$ = 57) | −0.04 ($n$ = 59) |

[*] $p \leq 0.05$.
[§] $p = 0.077$.

0.021; Fig. 1). Recipient requests occurred in 53 % of the dyads and were equally likely to occur between friends (36 %) and non-friends (54 %; $\chi^2 = 1.919$, $p = 0.364$). Recipient requests occurred in 22 % of all trials and increased the probability of the donor choosing the 1/1 option in these trials ($\chi^2 = 0.373$, $p = 0.001$; with request 87 %; without request 70 %). Therefore, we included the number of trials with recipient requests as a predictor in the linear model.

None of the independent variables differed significantly between the sexes (Table 1). There was a significant positive correlation, with a medium effect size, between participants' age and their visual regard, and a non-significant trend of a medium positive correlation between participants' age and their dominance rating. None of the other model predictor variables were correlated with each other (Table 2).

The linear model revealed a significant regression for the donors' prosocial tendencies ($R^2 = 0.431$, $F_{(10,29)} = 2.195$, $p = 0.048$; Table 3). Specifically, prosocial tendencies were negatively predicted by right-hand 2D:4D and the teachers' dominance score, suggesting that children with lower 2D:4D (i.e., higher prenatal androgen exposure) and lower dominance ratings had greater prosocial tendencies. We observed non-significant positive trends regarding the effects of the number of recipient requests and the donor's visual regard (Fig. 2). None of the other predictors were significant (Table 3). A model using the left-hand

**Table 3**
Results of the general linear model. Given are estimates, standard errors (*SE*), confidence intervals (*CI*), *t*-values, *p*-values, standardized coefficients (*Std Coeff*), and partial omega squared ($\omega^2$) for the intercept and each predictor of the model. Predictors with *p*-values ≤0.05 are highlighted in bold.

| Parameter | Estimate | *SE* | *CI* | *t* | *p* | *Std Coeff* | $\omega^2$[b] |
|---|---|---|---|---|---|---|---|
| (Intercept) | 53.52 | 22.91 | 6.66, 100.38 | 2.336 | 0.027 | −0.01 | – |
| Age | 0.72 | 0.93 | −1.18, 2.63 | 0.777 | 0.444 | 0.12 | 0 |
| Recipient requests | 0.61 | 0.32 | −0.04, 1.25 | 1.920 | 0.065 | 0.33 | 0.08 |
| Sex (male) | 1.60 | 2.32 | −3.15, 6.35 | 0.688 | 0.497 | 0.33 | 0 |
| **Right 2D:4D** | **−62.16** | **24.16** | **−111.57, −12.74** | **−2.572** | **0.016** | **−0.41** | 0.15 |
| Interaction partners | 0.80 | 0.80 | −0.84, 2.44 | 0.996 | 0.328 | 0.15 | 0 |
| Visual regard | 4.91 | 2.50 | −0.21, 10.04 | 1.962 | 0.059 | 0.32 | 0.08 |
| **Relative dominance** | **−0.09** | **0.04** | **−0.19, −0.00** | **−2.108** | **0.044** | **−0.58** | 0.10 |
| Relative dominance * Sex | 0.08 | 0.05 | −0.02, 0.19 | 1.615 | 0.117 | 0.51 | 0.05 |
| Friendship (no) | 0.30 | 1.99 | −3.76, 4.36 | 0.152 | 0.880 | 0.06 | 0 |
| Friendship * Sex | −3.69 | 3.28 | −10.39, 3.01 | −1.126 | 0.269 | −0.69 | 0 |

[b] Effect size is partial omega squared ($\omega^2$); large: $\omega^2 > 0.14$, medium: $\omega^2 = 0.06$–$0.14$, small: $\omega^2 = 0.01$–$0.06$.

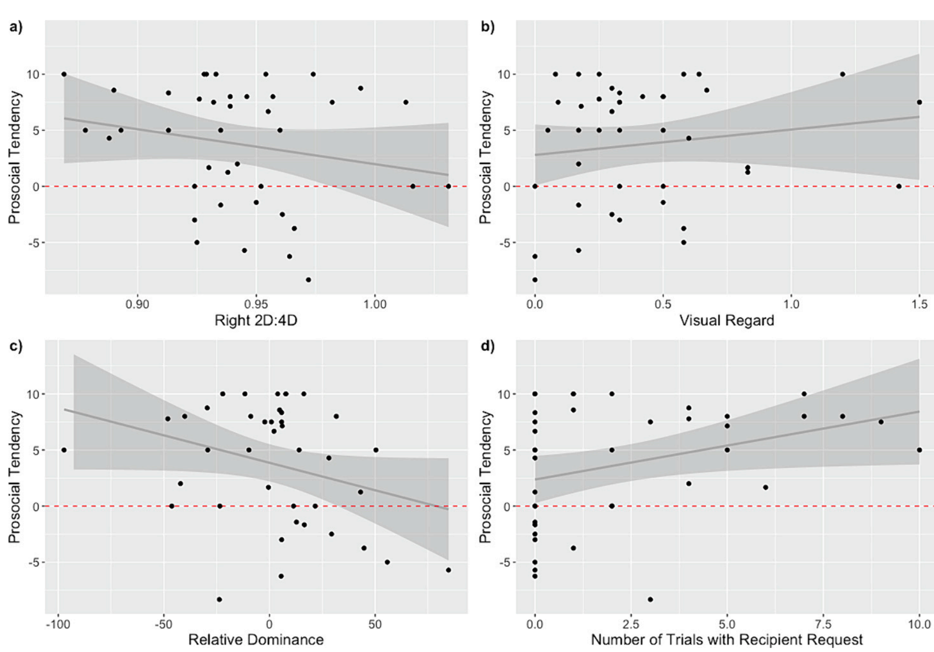


**Fig. 2.** The effect of donor children's (a) right 2D:4D, (b) visual regard, (c) relative dominance, and (d) number of trials with recipient requests on the children's prosocial tendencies. The dashed line indicates a prosocial tendency score of 0, meaning that the donor made an equal number of 1/1 choices in prosocial test and non-social control.

**Table 4**
Results of the general linear model with the children that showed full task comprehension ($n = 21$). Given are estimates, standard errors (*SE*), confidence intervals (*CI*), *t*-values, *p*-values, standardized coefficients (*Std Coeff*), and partial omega squared ($\omega^2$) for the intercept and each predictor of the model. Predictors with *p*-values ≤0.05 are highlighted in bold.

| Parameter | Estimate | *SE* | *CI* | *t* | *p* | *Std Coeff* | $\omega^2$ [b] |
|---|---|---|---|---|---|---|---|
| (Intercept) | 87.26 | 37.80 | 6.69, 167.83 | 2.308 | 0.036 | 0.05 | – |
| Recipient requests | 0.88 | 0.52 | −0.23, 2.00 | 1.686 | 0.113 | 0.39 | 0.10 |
| **Right 2D:4D** | **−93.08** | **40.81** | **−180.06, −6.10** | **−2.281** | **0.038** | **−0.63** | **0.20** |
| **Visual regard** | **7.78** | **3.27** | **0.80, 14.75** | **2.377** | **0.031** | **0.62** | **0.21** |
| Relative dominance | −0.11 | 0.06 | −0.24, 0.02 | −1.787 | 0.094 | −0.81 | 0.11 |
| Relative dominance * Sex | 0.09 | 0.07 | −0.06, 0.24 | 1.300 | 0.213 | 0.65 | 0.04 |

[b] Effect size is partial omega squared ($\omega^2$); large: $\omega^2 > 0.14$, medium: $\omega^2 = 0.06$–0.14, small: $\omega^2 = 0.01$–0.06.

2D:4D as a predictor instead of the right-hand 2D:4D showed similar results (see Supplementary material; Supplementary Table S1).

When testing the effects of these predictors with only the children who showed full task comprehension in the warm-up phase, we found comparable effects ($R^2 = 0.501$, $F_{(5,15)} = 3.009$, $p = 0.045$; Table 4). Donors' right-hand 2D:4D negatively predicted their prosocial tendencies. The negative effect of the relative dominance score was only a non-significant trend, whereas the positive effect of the donor's visual regard was significant in this sub-sample. None of the other predictors were significant (Table 4).

## 4. Discussion

The aim of the current study was to investigate 3–6-year-old children's prosocial choices when interacting with a familiar peer. We used a cost-free prosocial game to assess children's propensity to choose the prosocial 1/1 option over the selfish 1/0 option in the test condition with a recipient present, relative to a non-social control condition. We examined whether prenatal androgen exposure (approximated by 2D:4D), as well as children's prestige, dominance, and friendship predicted their prosocial tendencies. Additionally, we tested for the effects of donor sex, age, and recipient requests. Our results showed that 3–6-year-old children acted prosocially, by choosing the prosocial option significantly above chance and more often when a peer was present than when they were tested without a partner. Recipient requests occurred rarely (22 % of the trials), but they significantly increased the likelihood that the donor chose the 1/1 option. The donors' prenatal androgen exposure was related to their prosocial tendencies. Contrary to our predictions, children with lower 2D:4D (indicating higher exposure to prenatal androgens) behaved more prosocially. There were also marginal associations between the donors' prosocial tendencies and their visual regard as a proxy of their prestige (positive effect) and their teacher-rated dominance relative to the recipient (negative effect). Friendship and the donor's number of interaction partners during preceding live observations did not predict the children's prosocial tendencies.

Our findings that preschool children make prosocial choices corroborate earlier results with similarly aged children when tested in direct interactions with peers [40]. Anonymous paradigms, where the recipient is represented by a photograph or drawing, often fail to elicit substantial prosocial behavior in young children (e.g., [41]). The reason for these discrepant findings may be three-fold. First, young children's prosocial choices might be elicited by recipient requests (see [42]). Although recipient requests occurred in only 22 % of the trials in the current study, they significantly raised the likelihood with which the donors chose the 1/1 option in these trials. Overall, there was also a non-significant positive association between the number of trials with recipient requests and the donors' prosocial tendencies. These results speak for the recipient's ability to influence the donor's choices in direct interactions. Yet, due to the rareness of recipient requests, it is unlikely that they alone accounted for the children's prosocial choices. Second, children in anonymous settings may not fully comprehend that the picture represents a real person. Therefore, these settings may not reflect children's prosocial tendencies as adequately as real-life settings (see [43] for similar concerns in adults). Third, since children in the current study were tested with a peer from their social group, anticipated reciprocation or preceding interactions might have influenced their choices (cf. [44]). Our results in fact hint towards effects of children's relationships among their peers – particularly prestige and dominance – on their prosocial tendencies, thereby highlighting that it is not only ecologically valid, but also informative to test children's prosociality in interactions with familiar peers.

We found that lower right-hand 2D:4D (reflecting higher exposure to androgens in utero) predicted higher prosocial tendencies in a small, ethnically relatively homogeneous sample of children (mostly European descent; all White). The model run using left-hand 2D:4D yielded similar results. Although this result favors the assumption of a mediating role of prenatal testosterone exposure in the children's social decision-making, the direction of the effect contradicts our predictions. In line with evidence derived from parental reports on prosocial behavior in preschool children [3] and from prosocial choices of slightly older children in the same paradigm [17], we had predicted that children with higher prenatal androgen exposure would have a stronger tendency to withhold resources from their peers. Surprisingly, children's 2D:4D was not associated with any of our measures of prestige or dominance, as it has been found in adults (e.g., [10]). Nevertheless, our results that children with lower 2D:4D had higher preferences for the 1/1 option seem in line with studies showing that adults with lower 2D:4D are more likely to give a fair share and less likely to give either more or less than the fair share in economic games [20]. With the resource distribution used in the current study, choosing the 1/1 options might have been elicited by a normative preference for fair distributions (cf. [41]). It should be noted, though, that in the current sample there was high variation in prosocial tendencies in individuals with medium 2D:4D values and a particularly low sample size for high 2D:4D, which render the biological interpretation for this predictor difficult. Moreover, none of the 2D:4D measures (i.e., right-hand 2D:4D; left-hand 2D:4D; Dr–l) showed a significant difference between the sexes in our sample, although 2D:4D measures have been found to be sexually dimorphic from 2 years of age in larger samples [45,46]. The lack of significant sex differences in our study might stem from the small sample size (right hand: $n = 59$; left hand: $n = 56$). For example, the average sample size for studies testing for an association between 2D:4D and economic decision making reported by Parslow et al. [47] is $N = 262$, with a range from 86 to 704 participants. Moreover, for our main model, the final sample size was only $n = 40$ after excluding children who failed the warm-up and for whom we had not obtained all predictor variables. Considering endocrinological complexities and the mixed evidence for associations between 2D:4D and social decision making even in adults (e.g., [16,48]), large samples, at best collected longitudinally, will be necessary in the future to quantify the true biopsychosocial impact of prenatal androgen exposure on behavioral outcomes in children, especially in connection with their social relationships.

We found some indications that visual regard, a proxy of prestige in a social group [25], showed a positive association, and that teacher-rated dominance showed a negative association, with the children's prosocial tendencies. Although these two effects were not robust (i.e., they were each significant in one model, but only a non-significant trend in the other model), both were in line with our predictions. On the one hand, they parallel findings that 8–12-year-old children with high levels of visual regard were particularly prosocial when donating resources [6] and add to a large body of literature showing that various measures of high parental social status are associated with greater prosocial tendencies (e.g., [49]). It remains to be determined whether cost-free prosocial behavior adaptively facilitates prestige-based status acquisition and/or maintenance in young children or whether it is a by-product of a resource-rich (parental) environment. Also, costly actions merit further investigations. On the other hand, our results corroborate findings that preschool children who behave dominantly and prevail in resource conflicts donate fewer resources [7] and preferentially profit from unequal resource outcomes [28]. Due to time constraints during testing, we did not stage dyadic resource competition tasks with all participating children (cf. [28]), but relied on teacher-reported dominance among the peers. Yet, it is likely that teachers mainly drew on their observations of such overt and conspicuous resource conflicts in the group when assigning their dominance ratings (see [50]). Nevertheless, since the dominance ratings obtained from two different teachers were only moderately correlated in our study, it would be beneficial to add direct observations of resource conflicts as a measure of children's dominance in future studies. As expected, visual regard and dominance ratings were both positively related to children's age, whereas they were not correlated with each other and had opposite effects in the models. Cheng and Tracy [23] argue that social status is a multi-faceted construct that can be attained by freely conferred deference to popular individuals with valued abilities or traits (i.e., prestige) or by coerced deference to dominant individuals (i.e., dominance), both of which show distinct behavioral patterns and thus need to be investigated separately. Already preschoolers have been found to use different behavioral strategies to prevail in conflicts with peers (e.g., coercive vs. socio-positive behavior; [51]). Future studies need to further disentangle these factors and investigate the effects of prestige and dominance on prosocial behavior among familiar children more systematically.

Contrary to our predictions, friendship and the number of interaction partners had no effect on the donors' prosocial behavior in the prosocial choice task. Studies using prosocial choice tasks where the recipient is represented by a drawing or a puppet typically find that children are willing to donate more items to friends as opposed to disliked peers (e.g., [8]), although preferences for benefiting friends seem to vary with socio-cognitive capacities (e.g., Theory of Mind [52]). In contrast, real-life settings that include direct interactions with peers often fail to find an effect of friendship on resource allocations ([17,33]). Birch and Billman [41] showed that preschoolers shared more with friends than acquaintances because friends typically made more requests for the valuable items. In our study, however, recipient requests were equally likely to occur among friends and disliked peers, which might explain why friendship had no effect in our sample. Children's number of interaction partners, which we assumed to be another proxy for their popularity and prestige, did not show the expected positive association with children's visual regard or age in our sample (cf. [53]). Although inter-rater reliability was good for all observational measures, it is possible that in the preschool setting, where interactions between peers are often brief and less selective than interactions between older children, the number of interaction partners might not be a reliable measure of children's prestige in the group. Moreover, we only conducted two observation sessions per group, which might be too little to get a full picture of children's social relationships. To describe social dynamics and interaction structures among preschoolers more accurately, future studies should aim to conduct more observation sessions, over longer periods of time, and optimally supported by video recordings or automated tracking of interactions (e.g., [54]). This would allow more fine-grained analyses of children's social relationships and link empirical results more closely to children's rich everyday experiences [55].

The foremost limitation of our study was the small sample size, compounded by the fact that one third of the children failed to meet the initial, lenient criterion of choosing the payoff-maximizing 1/1 option in >4 of 8 trials in the warm-up without an interaction partner, when all the rewards went to themselves. This points to the fact the children had more problems with quickly understanding the task and making calculated choices in the warm-up phase and/or were more easily distracted than older children in the same paradigm [17]. When applying a stricter criterion for task comprehension (i.e., choosing the 1/1 option above chance level in the warm-up), we found that the children who failed this criterion were significantly younger than the children who passed it. Nevertheless, our procedure contained a secondary way to assess children's task comprehension, namely the non-social control condition. Both younger (3–4 years) and older children (5–6 years) chose the prosocial option significantly more often in the prosocial test than in the non-social control. These findings suggest that, although especially the younger participants initially struggled with making consistent, calculated choices in the 8 trials of the warm-up phase, they nevertheless demonstrated a basic comprehension of the task during the experiment. Nevertheless, future studies should have larger sample sizes, which would also allow zooming in on developmental effects in this age range.

In sum, we found that 3–6-year-old children behaved prosocially in a direct, peer-to-peer prosocial choice task, by preferentially choosing the option that equally benefited them and the recipient. Their prosocial tendencies were positively associated with their prenatal testosterone exposure (shown by a negative association with 2D:4D) and there were marginal associations with the donors' visual regard as a proxy of their prestige and their teacher-rated dominance relative to the recipient. Although our findings are qualified by a low sample size, they point to the crucial role of physiological and relational factors in the early development of children's prosocial behavior. Within their peer group, preschoolers are embedded in a complex social network that is affected by relationships and social standing. As such, research into the early development of any social behavior will profit from conducting investigations under real-life conditions facilitating naturalistic interactions, alongside laboratory studies, which offer more experimental control but are somewhat disconnected from individuals' lived experiences.

## Funding statement

This work was funded by the Austrian Science Fund [FWF; V-893 to LH; P26806 to JJMM] and by the University of Vienna [Marie Jahoda grant to LH]. The funders had no role in the study design, in the collection, analysis and interpretation of data, in the writing of the report, and in the decision to submit the article for publication.

## CRediT authorship contribution statement

**Lisa Horn:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Formal analysis, Conceptualization. **Sonja Windhager:** Writing – review & editing, Investigation, Formal analysis. **Nina Juricka:** Writing – review & editing, Investigation. **Thomas Bugnyar:** Writing – review & editing, Resources. **Jorg J.M. Massen:** Writing – review & editing, Funding acquisition, Conceptualization. **Gabriela Markova:** Writing – review & editing, Supervision, Conceptualization.

## Declaration of competing interest

None declared.

## Acknowledgments

We thank Ilke Akin Kilicarslan, Kim Sophie Rabenort, Katharina Riesinger, Hanna Schuh, Rashid Tellawi, and Anna-Maria von Bonin for their help with collecting the observational data. We thank the childcare organization Kindercompany for their support. We thank the parents, children, and childcare staff for their enthusiastic participation in the study. We further thank András Péter for apparatus design and construction, Nadja Kavcik-Graumann for drawing the illustration of the experimental set-up. Finally, we thank the editor and two anonymous reviewers for their valuable feedback on an earlier version of this manuscript.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.earlhumdev.2024.106055.

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