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# ‘Born this Way’? Prenatal exposure to testosterone may determine behavior in competition and conflict☆

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ABSTRACT

Fetal exposure to sex hormones can have long lasting effects on human behavior. The second-to-fourth digit ratio (DR) is considered a putative marker for prenatal exposure to testosterone (vs estrogens), with higher exposure resulting in lower DR. Even though testosterone is theoretically related to competition, the role of DR in human behavior is debated; and in situations such as bilateral conflict is unknown. We investigate this through a laboratory experiment using a repeated 2-person Tullock contest played in fixed same-gender pairs. Based on a previously obtained large sample of student subjects, we selectively invited participants to the laboratory if their right-hand DR was in the top (High-DR) or bottom (Low-DR) tercile for their gender. Unbeknownst to the subjects, we performed a controlled match of the DR types (Low-Low, Low-High, High-High). This novel methodology allows us to analyze the causal effect of DR on behavior for the first time in the literature. We find that Low-DR (vs High-DR) males compete more aggressively regardless of the counterpart’s type. For females’ conflict behavior, the counterpart’s type matters more than the decision-maker’s type: Low-DRs are non-significantly more aggressive but every-one is more aggressive against High-DRs. Limitations due to sample size are discussed.

## 1. Introduction

Extreme forms of competition, such as bilateral conflicts, are a ubiquitous part of our day-to-day life. From personal disputes to legal battles, and from religious or ethnic tensions to war between countries, humans are frequently involved in conflict situations with

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dramatic consequences. Examples include sports, competition for status (Charness et al., 2014), promotions (Orrison et al., 2004), rent-seeking (Tullock, 1980), and academic competition (Gomez-Mejia et al., 2009). Consequently, it is important to understand what triggers some people to be more aggressive than others in conflict. Heterogeneity in such behavior has various causes, including those commonly classed as nurture (e.g., upbringing, social norms, and stereotypes) or situational factors (e.g., socio-economic conditions, mental and physiological state). However, some part of it may also be influenced by nature: some people might be born with more conflictive inclinations than others. In this study, we focus on this ex-ante bio-sociological aspect.

More specifically, we focus on how competitive behavior may be shaped prenatally. Biological and psychological studies have shown that differences in fetal exposure to sex hormones (testosterone and estrogens) can explain some behavior in later life (Hines, 2006; Herbert, 2015). Our proxy for fetal hormone exposure is the relative length of the (right-hand) index finger compared to the ring finger, known as the second-to-fourth digit ratio (DR), with a higher relative fetal exposure to testosterone (FT) resulting in a lower DR (Goy and McEwen, 1980; Manning and Taylor, 2001). To investigate DR as an explanatory variable of conflict behavior, we conducted a controlled laboratory experiment using a multi-period 2-player contest game (Tullock, 1980). We use this game because in the literature it is considered to be reflecting conflictive situations better than other competitive games such as Cournot, Bertrand, Centipede, Beauty contest, etc.[1] Crucially, we investigate how (repeated) interaction of different FT types affects dyadic competition outcomes.

Based on a previously obtained large sample of DR measures, we selectively invited only High (H) and Low (L) DR type subjects to our experiment. Unbeknownst to the subjects, we thus performed a controlled match of types as opponents in the contest – as either H-H, L-L, or H-L. We define a subject's type as H (L) if they are in the top (bottom) tercile of the DR distribution within their gender. Because DR is sexually dimorphic, its relationship to behavior is more meaningful for interactions with a member of the same gender. Moreover, conducting single-gender experimental sessions have the benefit of controlling for subjects' expectations of opponents' gender, to avoid subjects purposely moderating their competitive behavior – e.g., males being less competitive in the presence of female subjects (Van den Bergh and Dewitte, 2006) or more likely to compete with other males (Datta Gupta et al., 2013). For these reasons, we designed our experiment as an intra-gender anonymous competition for monetary resources.

We find that L-type males spend significantly higher conflict effort than H-type males, regardless of the counterpart's type. That is, they are more aggressive. The outcome is that anybody matched with an L-type earns significantly less compared to when the counterpart is an H-type. When two L-type males are matched, we observe the highest individual conflict effort and the highest aggregate conflict levels. These findings are in line with our hypothesis that higher exposure to testosterone is related to more aggressive male behavior, based on the theoretical role of testosterone for human competition (e.g., Booth et al., 1989). The results are more intricate for the females: overall every-one is more aggressive against H-types. While the highest conflict effort for females is exerted by L-types when matched with H-types, matching two L-types results in the lowest aggregate conflict levels – exactly the opposite as for males.

This paper contributes to the existing literature in several ways. First, as we show in the literature review below, the effects of the prenatal exposure to testosterone on later life behavior is mixed. Moreover, the studies that do find a relationship often provide correlational evidence. This is the very first study that provides causal evidence of the effects of FT on competitive behavior. Our study uses individual information on prenatal exposure to testosterone to match subjects in the laboratory, which means that our same- and opposite-type pairs are defined exogenously *by design*. Second, previous studies reported that Low DR is associated to success in competitive scenarios (e.g., in financial trading, Coates et al., 2009, and sports, Manning and Taylor, 2001). However, these studies cannot assess whether Low-DR individuals prevail due either to superior competitive preferences or superior skills. Our study uses a contest game where differences in skills play a marginal, if any, role. Hence, our setup lets us isolate the effects of FT on conflict behavior regardless of individual differences in personal abilities. Third, we contribute to the contest theory literature incorporating biological factors for the first time. Finally, we contribute to the literature on gender differences in competition by reporting the (surprising) finding that males act primarily in accordance with their own biological type whereas females mostly react to their rival's type.

Viewing competition outcomes as a function of biological types can provide novel explanations for patterns observed in markets, organizations, and society. When certain types are more likely to select into certain professions, such as financial trading (Sapienza et al., 2009) or entrepreneurship (Nicolaou et al., 2018), this will affect the nature of the competition. The nature of the competition, in turn, may also attract or favor the survival of certain types. Having a type suited to a particular competitive environment may be so important as to be part of human adaptive machinery: Cecchi and Duchoslav (2018) show that the exposure of pregnant women to violent conflict in Uganda resulted in children born with lower DRs, who cooperate less in a public good game. These findings hint at a biological feedback mechanism that may contribute to vicious circles in conflict-prone societies. If we are to break such vicious circles, understanding the feedback mechanisms that propagate overly competitive or conflictive behavior is of key importance.

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[1] The two-player setting does not need to elicit more competitive behavior than a multiplayer contest. However, we consider the two-player case as it allows for more control on important factors such as the other player's characteristics and behavior. Moreover, a multiplayer setting would require a much larger number of participants, which in our case is limited by design, as shown below (i.e., inviting participants from a previous experiment involves attrition, so increasing the number of observations in the final experiment would require a huge sample in the previous one).

## 2. Literature review

### 2.1. Prenatal testosterone and DR

Our main interest is the effect of prenatal exposure to testosterone. Besides its primary function in the development of male reproductive organs, prenatal testosterone plays a key role in the 'masculinization' of the fetal brain (Arnold and Breedlove, 1985; Bao and Swaab, 2011; Goy and McEwen, 1980; Herbert, 2015), with male fetuses producing, and therefore being exposed to, much higher levels of testosterone than female fetuses (Rodeck et al., 1985; Finegan et al., 1989). Patients with androgen-related syndromes provide quasi-experimental evidence: males with Androgen Insensitivity Syndrome (unresponsive androgen receptors) have not only the outward appearance but also psychological traits characteristic of females, while females with Congenital Adrenal Hyperplasia (increased androgen production) display childhood play behaviors that are more typical of males (see Hines, 2006; Herbert, 2015). Despite these patients receiving postnatal treatments that address hormonal imbalances, the effect on sex-differentiated behaviors persists. Moreover, even naturally occurring levels of testosterone are correlated with sex-differentiated infant behaviors (Hines et al., 2002; Udry et al., 1995). A key implication of this evidence is that prenatal testosterone exposure predicts post-natal behavior in both males and females.[2]

Our marker of prenatal hormone exposure is the digit ratio (DR). The DR, also known as the second-to-fourth DR or 2D:4D, is the ratio of the length of the index finger to the length of the ring finger. There is evidence of a negative correlation between the DR and exposure to prenatal testosterone in humans[3] based on, e.g., testosterone levels in amniotic fluid (Lutchmaya et al., 2004; Ventura et al., 2013), androgen spillovers in dizygotic twins (van Anders et al., 2006), and individuals with androgen-related syndromes (Brown et al., 2002; Berenbaum et al, 2009; Manning et al., 2013). The DR is a seemingly stable proxy – it can be measured reliably after 3 months of fetal gestation (Galis et al., 2010; Malas et al., 2006) and is consistent throughout childhood and adulthood (Garn et al., 1975; Manning et al., 1998; McIntyre et al., 2005; Trivers et al., 2006). In addition, the DR is sexually dimorphic, i.e., males tend to have lower average DR than females (although distributions largely overlap). Due to its apparent stability and relative ease of measurement, the DR has become a popular proxy for researchers investigating the effects of prenatal physiology on adult behavior. However, it is also true that the reliability of the DR as a proxy for prenatal exposure to sex hormones has been recently challenged (e.g., Leslie, 2019; Nave et al., 2021; Richards, 2017); some of these critics have proved theoretically wrong (Manning and Fink, 2017) or empirically unsupported in large samples (e.g., Butovskaya et al., 2021). The debate remains open.

### 2.2. DR and competitive behavior

In line with the hypothesis that testosterone plays an important role for competition in humans, the DR has been shown to correlate negatively with various competition-related traits outside the laboratory, although null findings exist. Studies show relationships with psychological measures such as a desire for dominance (Neave et al., 2003; Manning and Fink, 2008), aggression (Bailey and Hurd, 2005; Benderlioglu and Nelson, 2004; Turanovic et al., 2017; but see Hilgard et al., 2019), and self-reported competitiveness (Bönte et al., 2017). The literature also documents relationships with professional outcomes such as performance in athletes (Bennett et al., 2010; Tester and Campbell, 2007) and trading styles and profits in financial professionals (Coates and Herbert, 2008; Coates et al., 2009; Cronqvist et al., 2016). Furthermore, some professions appear to attract certain DR types. For example, Sapienza et al. (2009) find that Low-DR individuals are more likely to self-select into financial services jobs, while Nicolaou et al. (2018) find the same relationship for entrepreneurship (but see Fossen et al., 2021, for null results). These suggest that interactions in certain markets and professions may be more "testosterone-driven", due to specific DR types both selecting into these interactions and prevailing in the long run (Bönte et al., 2016; Dabbs and Dabbs, 2000; Coates et al., 2010). Critically, however, significant links between DR and behavior/traits tend to appear in smaller samples, indicating potential publication biases (Fossen et a., 2021; Neyse et al., 2021), yet there exist significant results also using very large samples (see e.g. Finley et al., 2022, with about 7 k observations for risk taking, doubling the sample size in Neyse et al., 2021).

The study closest to ours is the first price sealed-bid auction experiment by Pearson and Schipper (2012), who investigate the *correlation* between DR and bidding behavior in pairs of subjects (stranger matching) in which the gender of the counterpart was unknown (experimental sessions contained both males and females). Based on prior research on the relationship of DR with risk taking and aggression, they hypothesized that L DR individuals will bid higher amounts. But they find no evidence of such a relationship. The authors speculate that such effects may either be non-existent or too small, as well as reflecting that "*the 'aggression' motive may not be present in the auction because subjects may view it more like an individual decision task*" (p. 526, quotation marks in original). Our experimental set-up is arguably more conducive to conflictive behavior, by deliberately matching extreme DR types for multiple periods in a partner design, conducting single-gender sessions, and using a Tullock all-pay contest instead of a winner-pay auction.

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[2] Although the evidence is strongly suggestive of testosterone-driven masculinization in utero, it is still unclear whether fetal testosterone levels are also related to other factors that affect the child's upbringing. Note, for example, evidence that fetal and maternal testosterone levels are positively correlated (Gitau et al., 2005; but see also Rodeck et al., 1985) and of a negative correlation between a mother's DR and the likelihood of having a son (Kim et al., 2015).

[3] See Brañas-Garza et al. (2018) for an extensive discussion.

### 2.3. Contest literature

A unique feature of many situations in competition and conflict is that the agents involved spend costly resources such as physical effort, time, or money to win a prize. Irrespective of the outcome they lose the resources spent, i.e., the costs are irreversible. Contest Theory is the area of game theory that investigates this type of games (Konrad, 2009). The application of this area of research includes, among others, promotional tournaments, rent-seeking, innovation races, legal battles, and sports. An important feature of any contest is the rule that determines how the probability of winning depends on the resources spent (henceforth, 'efforts'). A function that maps the vector of efforts into probabilities of winning is called a Contest Success Function or CSF. The CSF introduced by Tullock (1980) considers a winning probability proportionate to the effort spent for each player – similar to a lottery. Due to its theoretical tractability as well as applicability in various contest situations, it is one of the most popular CSFs.

Since it is easily implementable in the laboratory and easy for the subjects to understand, the Tullock (1980) contest is also the most popular setting in the experimental literature (Dechenaux et al., 2015). Researchers have employed this contest to investigate rent-seeking (Potters et al., 1998), gender differences (Price and Sheremeta, 2015), group conflicts (Abbink et al., 2010), and identity related conflict (Chowdhury et al. 2016) to name a few.

A robust phenomenon in experimental Tullock contests is 'overbidding'. That is, subjects typically spend more effort (or bid more) than the level predicted by the Nash equilibrium with selfish preferences (Dechenaux et al., 2015). Several behavioral factors, such as joy of winning, errors, social preference, and experimental design are argued to be responsible for overbidding (Sheremeta, 2013; Chowdhury et al., 2020). No experiment to date, however, has investigated the role of biological factors such as hormones for contest behavior.

## 3. Experimental procedure and hypotheses

### 3.1. Theoretical benchmark

To replicate conflict behavior in the lab, we introduce a contest. with two identical players. Player $i$ (with $i = 1,2$) chooses his effort $e_i \in [0, B]$ from budget $B$ to win a prize of common value $V > 0$. There is no prize for the loser and, irrespective of the outcome of the contest, players forgo their efforts. The probability that player $i$ wins, $p_i(e_1, e_2)$, is represented by a lottery CSF (Tullock, 1980):

$$p_i(e_1, e_2) = \begin{cases} e_i/(e_1 + e_2) & if \ \ e_1 + e_2 \neq 0 \\ 1/2 & otherwise. \end{cases} \tag{1}$$

That is, the probability of winning depends on player $i$'s own effort relative to the sum of both players' efforts. Given (1), the expected payoff for player $i$, $E(\pi_i)$, can be written as:

$$E(\pi_i) = p_i V + (B - e_i) \tag{2}$$

where $(B - e_i)$ is the left-over budget after expending effort. It can be shown directly from the literature that a Nash Equilibrium in pure strategies exists (Szidarovszky and Okuguchi, 1997), and it is unique (Chowdhury and Sheremeta, 2011). Following standard procedure, the unique Nash equilibrium effort for risk-neutral players with selfish preferences is:

$$e^* = \begin{cases} V/4 & if \ \ B > V/4 \\ B & otherwise \end{cases} \tag{3}$$

In our experiment we set $B = V$ to ensure the interior solution, and the equilibrium payoff is $\pi^* = B + V/4$. The equilibrium effort remains the same for finite repetition of this game. We set the endowment and the prize value at 180 tokens ($B = V = 180$), and hence the equilibrium effort is 45 tokens in each period.

### 3.2. Experimental design and procedure

The current study has two distinct innovative aspects: the investigation of conflict behavior and its relation to the DR, and the matching mechanism of subjects in the experiment. The latter feature is embedded in our experimental procedure. We ran six treatments in which subjects play exactly the same contest game. The variation, however, comes from how the subjects are matched in different treatments. We matched a particular DR type (H or L) of subject to another without the knowledge of the subjects, and separately for each gender. Since we manipulated matching between DR types, ours is not a standard correlational study, in contrast to the DR-behavior literature. Below we explain the matching mechanism in detail.

We recruited the subjects in two stages. First, 920 subjects were recruited from the LSE Behavioural Research Lab's subject pool for an experiment without any eligibility criteria or exclusion restrictions. During this experiment, subjects performed a set of tasks (described in Galizzi and Nieboer, 2015, and Brañas-Garza et al., 2018).

At the end of the experiment, the monitors led subjects into a separate room where we had set up a computer with a high-resolution scanner (Canon LIDE 110). Subjects were asked to read an informed consent form, in which we explained the procedure of obtaining the DR. If the subject agreed to provide a DR measure by signing the informed consent form, our research assistant scanned both hands to obtain the DR. In total, we obtained DR scans for 704 subjects (226 males, 478 females).

The right-hand DR of each subject was computed following the procedure of Neyse and Brañas-Garza (2014). We then grouped subjects by gender and ranked them according to their DR. Within each sample, we categorized subjects into 3 terciles according to their DR. Approximately a semester after collecting their DR, we invited only subjects in the top and bottom DR terciles (i.e., within-gender H and L types) back to the laboratory for our contest experiment. The invitation for this experiment was sent through the LSE subject recruitment system and followed the standard invitation format. Specifically, the email did not mention (i) any detail of the experiment, (ii) that only subjects who had participated in the earlier experiment were invited, (iii) that participation was restricted to those with H and L DR, or (iv) that only same-gender subjects were to be matched. There was no indication that any subject suspected that the invitation was contingent on their earlier participation, or in any way related to the DR measure they had provided. Our final sample consists of 70 male and 74 female subjects.

Note that this protocol necessarily entails some attrition we could not control. The initial maximum number of males in the experiment was 150 (i.e., 2/3 of the 226 males with DR data) whereas for females this figure was 320 (2/3 of 478). In order to get gender balance, we invited all the 150 males and 150 females selected at random from the 320 (half of each tercile): 47 % of males and 49 % of females finally showed up.[4]

Unbeknownst to the subjects, we performed a matching of H and L types as opponents in the contest game. Hence, we implemented a 3x2 factorial design {L vs L, L vs H, H vs H} × {Male, Female}.[5] This design allows us to analyze the data using the decision maker's and the counterpart's type, and their interaction, as explanatory variables. However, the whole process results in a different number of subjects in the different treatments. Note that controlling for both players' DR types in the regression analysis alleviates concerns about lack of between-treatments balance but does not fully eliminate them. In the Results section, we provide an in-depth discussion on statistical power. Table 1 summarizes the treatment details and number of observations.

Each subject took part in only one session of a 15-period contest while fixed-matched with another subject. In each treatment each subject was given 180 tokens per period (i.e., $B = 180$) from which s/he could bid for a prize of 180 tokens (i.e., $V = 180$). Hence, the theoretical equilibrium bid was ($e^* = 180/4 =$ ) 45. Players could enter bids up to one decimal place. All sessions were run using z-Tree (Fischbacher, 2007).

For each session, which were always of same gender, we recruited equal numbers of H and L types. Using the ID code assigned by the subject recruitment system, we could identify a subject's type upon arrival at the laboratory. After taking note of the numbers of H and L types present, we randomly allocated subjects to a computer cubicle in the laboratory. By asking subjects to provide their ID code in a computerized questionnaire at the start of the experimental session, we identified which computer cubicles had an H-type and which cubicles had an L-type. This information was crucial for the next step: matching L and H-types in the 2-player contest. To ensure sufficient anonymity in the laboratory, sessions with lower sign-up rates of H and L types were supplemented with 'filler' subjects that did not attend the first stage sessions (and for which we do not have a DR measure).

Each subject participated in only one session and had not participated in a contest experiment before. Instructions, which can be found in the Supplementary Materials, were read aloud by an experimenter. Subjects were paid the combined earnings of five randomly chosen periods (with an exchange rate of 2 tokens for £0.01). Before the payments were made, subject demographic information was collected through an anonymous survey. Each session took about 1 h and average earnings per subject were £14.96.[6]

### 3.3. Hypotheses

Given the literature on (prenatal) testosterone and competition reviewed above, we coin the following hypotheses based on the decision maker's and counterpart's DR types:

1. A higher FT exposure, reflected by a lower DR should result in more aggressive behavior in conflict. Thus, we expect higher bids in the experiment by L-type (vs H-type) decision makers, irrespective of the counterpart's type, which should be evident in the first period.
2. Someone matched with an L-type (vs H-type) should bid more irrespective of their own type, as a reaction to the L-type's higher bids (Hypothesis 1). However, this should not be the case in the first period bid, as the bid of the other player is not observed. Moreover, controlling for the counterpart's bid in the last period (as a proxy for the expected bid in the current period) should eliminate the effect of the counterpart's type on bids.

Whereas Hypothesis 1 comes directly from the DR literature, Hypothesis 2 comes from the contest literature where instead of

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[4] Note that we have no access to data other than DR for those not participating in our experiment (we do not own the data from the initial sample). Thus, we can only check self-selection bias using DR. For three of the four subpopulations invited we find no significant difference between the DRs of those invited and of those who finally participated. The only significant difference arises for the L DR females: those participating had lower DR than the invited subjects (mean DR: 0.934 vs 0.945, p=0.04, two-tailed Mann-Whitney *U* test; all remaining comparisons yield p>0.15). At least in terms of within-gender DR differences, hence, there seems to be little selection bias.

[5] The DR distribution is different for males and for females: the mean (SD) DR in our final sample is 1.010 (0.020) and 0.994 (0.013) for H type females and males, respectively, whereas it is 0.934 (0.024) and 0.925 (0.020) for L type females and males, respectively.

[6] We also ran an additional 15-period Tullock contest, for which we re-matched the subjects. The data from this additional contest is out of scope for the current study (matching was no longer controlled) and, crucially, subjects did not know about the second contest until the first contest had finished. Hence, for the purpose of this paper we will consider only the first part of the experiment (15 periods before the rematch) and no filler subjects.

**Table 1**
Summary of Treatments.

| Treatment name (Number of subjects) | | Matching type | | |
|---|---|---|---|---|
| | | High vs High | High vs Low | Low vs Low |
| **Gender** | Male | Male-HH<br>(20) | Male-Mixed<br>(34) | Male-LL<br>(16) |
| | Female | Female-HH<br>(28) | Female-Mixed<br>(24) | Female-LL<br>(22) |

following an inverted U-shaped best response, in the laboratory subjects often replicate their opponent's behavior. This myopic behavior is reflected when a lagged bid of the opponent has a positive effect on own bid (see, e.g., Chowdhury et al., 2018). These hypotheses are expected to hold especially among males, given the literature on (prenatal) testosterone and male-male competition (Booth et al., 1989). Previous studies suggest that the results may in fact differ by gender (Herbert, 2018).

## 4. Results

To economize on notations, the case of an H-type playing against another H-type is denoted as *HH* and that of an L-type against an L-type as *LL*. For *Mixed* pairs, the variables referring to an H-type when playing against an L-type are denoted as *HL* and those referring to an L-type against an H-type as *LH*.

Furthermore, we use Ø to refer to the aggregation of L and H-types. Specifically, the case of L (H) type players when playing against either type (that is, independent of the opponent's type) is denoted by *LØ* (*HØ*), whereas the aggregation of both types (that is, independent of the decision-maker's type) when playing against L (H) type players is denoted by *ØL* (ØH).

### 4.1. Aggregate behavior

We start by reporting the aggregated bid spent by the subjects, separated by matching category (treatment) and by gender. The top panel of Fig. 1 shows the Kernel density function for the aggregate data over the 15 periods: *LL* (in solid red), *HH* (in solid blue), Mixed (aggregating *HL* and *LH*: in dotted orange; they are disaggregated in the small-embedded figures for visual clarity) for males and females separately. The lower panel shows the same for only the first period. Table 2 provides the descriptive statistics for these cases.

As can be seen in the top panel of the figure (all periods), among males the bid distribution for *LL* pairs is shifted to the right side of the bid distribution of the *HH* pairs. Furthermore, the peak for *HH* pairs is at a much lower bid than the peak for *LL* pairs (approx. 45 vs 90; note that 90 is the equilibrium for relative-payoff-maximizing players). The *Mixed* pairs bids are somehow in the middle with dual modes close to the aforementioned peaks; yet, as can be seen in the small-embedded figure, the peak at 90 is entirely due to *LH*. This provides the very first indication that, for males, the *LL* pairs bid more aggressively compared to their *HH* counterparts and that high bids are mainly observed for L DR decision makers, in line with Hypothesis 1. Among females, however, different patterns arise. *HH* and *Mixed* pairs show a peak at a high level of bidding (again, 90, which for the *Mixed* pairs results from the combination of a peak at 95 for *LH* and a peak at 85 for *HL*, although the latter also shows an intriguing peak at 20 which corresponds to the best response against bids between 136 and 138), while *LL* results in a bimodal distribution (with peaks at about 45 and 90). Since almost all the treatments show overbidding, it is unlikely that the subjects are best responding their opponent's bids. However, the bimodal distribution for females in *LL* indicates that some females (although not best responding according to the theory) might reduce their bid as a result of the high bid of the opponent.

Note that an aggregate distribution of bids over the 15 periods may arise not only due to decision maker's own competitive disposition but also as a reaction to the opponent's bidding behavior. To tease out the response part, we also plot the bids distribution considering only the first period in the bottom panel of Fig. 1.

For males, the resulting distributions are qualitatively similar compared to the aggregate results; i.e., the peak for *LL* pairs is well above that for *HH* pairs, with *Mixed* pairs displaying a bimodal distribution (and the high-bid peak being only due to *LH*). But the bid distribution in the first period is not much different for the different pair types among females (although there seems to be a higher peak for *LH* than *HL*). This suggests that while males bid mainly according to their DR type so that differences arise already in the first period, the aggregate differences among female pair types develop over time, potentially reflecting the effect of the individuals' reactions to their counterpart's behavior.

The descriptive statistics in Table 2 are broadly in line with the observations from Fig. 1. Furthermore, the table shows that L DR males bid more than H DR males (i.e., *LØ* vs *HØ*) in the first period and overall. The difference between the mean bids of L and H DR males is in fact nearly identical when considering either the 15 periods or only the first one (i.e., about 13 tokens difference). That difference goes in the same direction for females, although is smaller in size. As expected, for both males and females, there is no apparent difference in the first period bids when playing against the L and H DR individuals (i.e., *ØL* vs *ØH*). But overall, L DR males seem to face larger bids than H DR males, whereas the result is the opposite, and the difference is stronger, for females.

The observations above indicate that even without interaction there appears to be an effect of FT on behavior, in particular among males. For females, however, the effect of FT appears to be indirect and arising as the interaction develops: different DR types face different overall bids from their opponents. For males, these preliminary results are in line with Hypotheses 1 and 2, although weakly in the latter case. For females, the data go weakly in favor of Hypothesis 1 and strongly *against* Hypothesis 2. To understand this better,

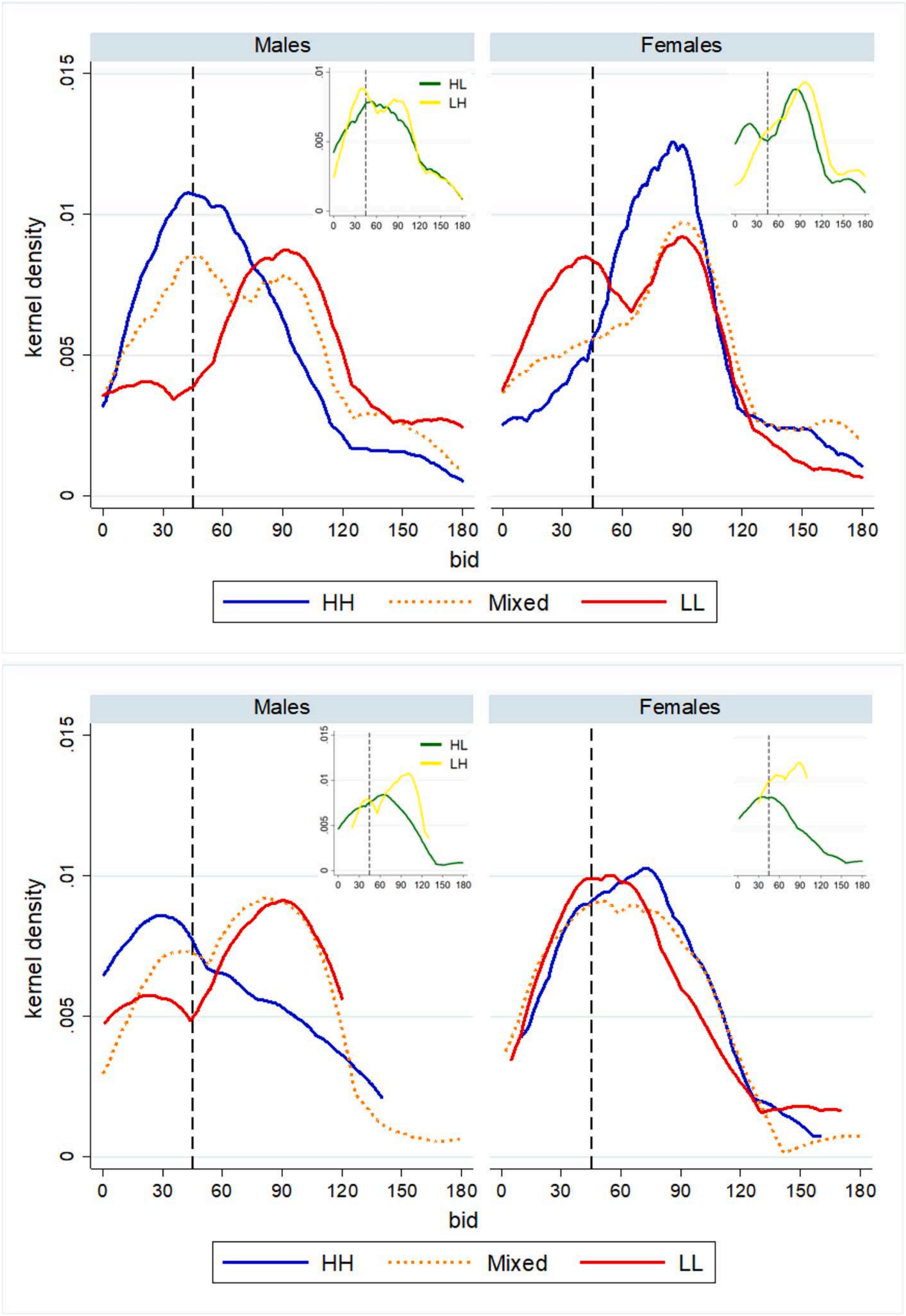

**Fig. 1.** Distribution of bids across conditions: Males and females, **Note:** The top plot refers to all 15 periods collapsed, whereas the bottom plot refers to only the first period. In both plots, the left panel displays the kernel density of bidding for males across the three matching treatments (HH, Mixed, LL; the small-embedded figures disaggregate the Mixed condition into HL and LH), whereas the right panel displays the same for females. The dashed vertical line shows the Nash Equilibrium bid, 45.

we look at the dynamics of behavior and conduct regression analyses to assess statistical significance. We perform our analyses in two steps. First we analyze bids, then we look at the absolute outcomes of the contest (i.e., payoffs).

### 4.2. Dynamics of bidding

Figs. 2 and 3 show the dynamics of bidding behavior for males and females. The top right panel refers to the comparison between *L* and *H* decision makers (*LØ* vs *HØ*), regardless of the opponent's type. The bottom right panel refers to the comparison between *L* and *H*

**Table 2**
Average (standard error) bids.

| | Males | | Females | |
|---|---|---|---|---|
| **Case** | **Allperiods** | **Firstperiod** | **Allperiods** | **Firstperiod** |
| **LL** | 83.63(9.04) | 62.94(9.76) | 66.26(8.37) | 67.27(8.98) |
| **HH** | 61.26(7.86) | 52.35(9.38) | 79.35(6.67) | 66.68(6.62) |
| **Mixed** | 71.10(5.77) | 68.53(6.75) | 79.02(6.90) | 64.30(7.89) |
| **LH** | 73.40(6.31) | 75.88(7.85) | 88.16(7.56) | 69.69(7.22) |
| **HL** | 68.80(6.91) | 61.18(10.82) | 69.88(7.32) | 58.92(14.01) |
| **LØ** | 78.51(5.37) | 69.61(6.28) | 77.21(6.21) | 68.13(6.31) |
| **HØ** | 65.03(5.22) | 56.41(7.09) | 74.62(5.09) | 64.35(6.23) |
| **ØL** | 76.21(5.67) | 62.03(7.25) | 68.07(5.81) | 64.32(7.60) |
| **ØH** | 67.33(5.15) | 63.16(6.48) | 83.76(5.11) | 67.58(5.09) |

**Note:** Robust SE clustered at the pair level are in parentheses.

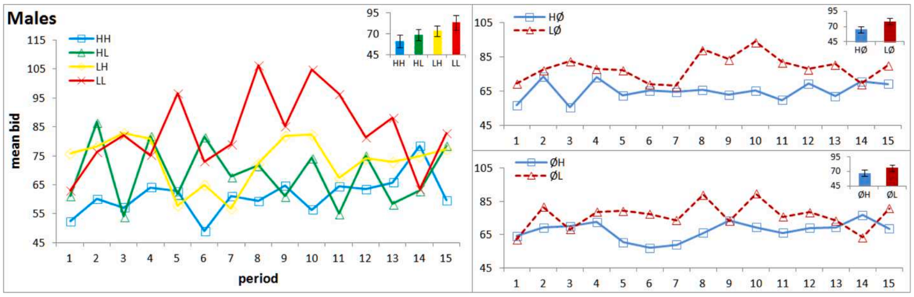

**Fig. 2.** Dynamics of mean bids: Males, **Note:** Top right panel compares bidding of L (LØ) vs H (HØ) decision makers. Bottom right panel compares bidding when the decision maker's opponent is L (ØL) vs H (ØH). Left panel displays bidding across the four conditions (HH, HL, LH, LL). Small-embedded figures show mean bids collapsed across periods (error bars display SEM clustered at the pair level).

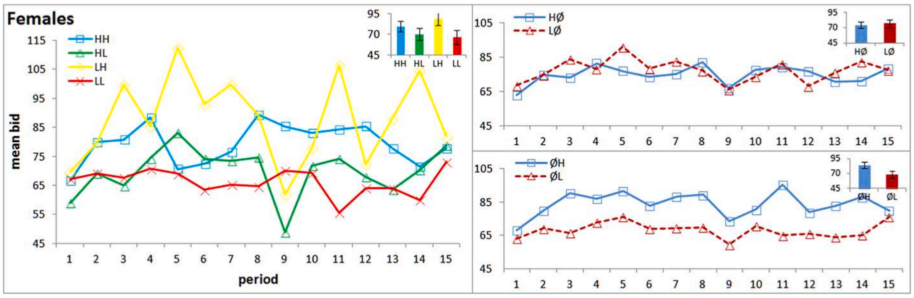

**Fig. 3.** Dynamics of mean bids: Females, **Notes:** See notes in Fig. 2.

opponents (*ØL* vs *ØH*), regardless of the decision maker's type – i.e., how overall subjects behave against type L or type H, irrespective of their own type. The left panel displays the mean bids in each of the four possible conditions ($HH, HL, LH, LL$). The small-embedded figures display the corresponding mean bid collapsed across periods (analogous to Fig. 1 and Table 2 above). In all cases, the horizontal axis cuts the vertical axis on the Nash equilibrium (i.e., bid = 45).

Focusing on the right panels of Fig. 2, note (in line with earlier observation) that among males, L-types bid more than the H-types. This is true overall as well as for the very first period, which aligns well with Hypothesis 1.[7] Note also that the bids against type L and H are similar to each other in the first period, although L rivals seem to trigger higher bids than H rivals when considering all periods. Hence, we also observe considerable support for Hypothesis 2. The left panel in Fig. 2 provides further intuitions. *LL* pairs bid more than their *HH* counterparts – both overall and in the first period. Moreover, although it is not the case in the first period, the ranking of mean bids across pair types ($HH < HL < LH < LL$) matches the expected patterns considering Hypotheses 1 and 2 together, with the effect of the counterpart's type on bids (Hypothesis 2) being weaker than that of the decision maker's type (Hypothesis 1).

For females, the results are more complex. Observe in the top right panel of Fig. 3 that the bids by L-types are slightly above but are very similar to those of H-types – both in the first period and overall. This also goes in line with Hypothesis 1, albeit very weakly.

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[7] We provide statistical tests with GLMM regressions and a formal result below.

However, as shown in the bottom right panel, bids against the H-type are higher than bids against the L-types overall, in clear contradiction to Hypothesis 2. Understandably, the bids against different types are not different in the first period since the opponent's behavior can only affect one's own behavior as the experiment develops. Also, as shown in the left panel of Fig. 3, whereas L females show higher bids than H females in mixed pairs (i.e., *LH* vs *HL*), the *HH* pairs bid more than the *LL* pairs, indicating strong response effects.

Tables 3 and 4, respectively for males and females, investigate bidding behavior using a mixed-effects multilevel regression (GLMM) with random effects at the pair and individual levels to control for dependence within pairs and individuals. These results are consistent with the figures above. Indeed, in the case of males, L-types bid significantly more than H-types ($M_{LØ}=78.51$, $M_{HØ}=65.03$, $p = 0.03$ in column 1, i.e., controlling only for time trend).[8] Males also bid more when paired with an L compared to an H opponent, but not significantly so ($M_{ØL} = 76.21$, $M_{ØH} = 67.33$, $p = 0.16$). Thus, we find partial support for Hypotheses 1 and 2 among males (not significant in the latter case). For females, there is no significant difference in bidding between L and H decision makers ($F_{LØ}=77.21$, $F_{HØ}=74.62$, $p = 0.61$) although, in line with Hypothesis 1, L-types bid slightly more.[9] Yet, females bid significantly less against L than against H opponents ($F_{ØL} = 68.07$, $F_{ØH} = 83.76$, $p < 0.01$), in sharp contrast to Hypothesis 2.

The interaction between the decision maker's type and the opponent's type (*LØ x ØL*) is insignificant for both males ($p = 0.87$, column 2) and females ($p = 0.47$). This means that, for either gender, the effect of the decision maker's type on bids is similar when playing against L and H opponents, whereas the effect of the opponent's type is similar among L and H decision makers.

In our next model specification, we control for various strategic variables such as the bids of both players in the previous period, and whether the decision maker won the prize in the previous period (the first period is not considered; see columns 3 and 4 of Tables 3 and 4), as is standard in the literature on repeated contest games (Dechenaux et al., 2015). The results for males are not qualitatively affected ($p = 0.04$), yet the coefficient is reduced by 20 % (this is an expected reduction stemming from the fact that controlling for previous bids entails estimating changes in bids rather than absolute bids).

Similarly happens among females: the effect of the decision maker's type remains non-significant ($p = 0.40$, column 3, Table 3) and he remaining results regarding main or interaction effects are barely affected, in terms of significance, by the inclusion of these controls. It should be mentioned that controlling for the opponent's past behavior reduces the effect of the opponent's type on females' bids by 15 % but does not fully eliminate it (the coefficients of *ØL* in columns 1 and 3 are 15.4 and 13.1, respectively, and both are significant, $p < 0.01$). This is somewhat intriguing because any effect of the opponent's type on bids can only arise indirectly as a response to the opponent's behavior. Thus, this result suggests that the participants' response to the opponent's behavior does not only consider his/her bidding behavior in the last period (as a continuous variable); more complex considerations seem to be in place. However, our sample size limits us to explore other potential considerations (such as whether one player's bid exceeded the other, whether particular thresholds are considered, etc.) as exploratory analyses would be clearly underpowered.

Next (columns 5 and 6), we also control for the decision maker's age, intuitive (vs reflective) cognitive style (Bosch-Domènech et al., 2014; Sheremeta, 2018), risk preferences (Brañas-Garza et al., 2018; Chowdhury et al., 2014), and body mass index (Fink et al. 2003) as potential confounding factors. The results remain nearly identical to those obtained from columns 3 and 4, although we lose a non-negligible number of observations due to missing values, especially among males (12 males and 1 female are excluded from the analyses).[10]

In sum, for both genders, L-type subjects appear to bid more aggressively than H-type subjects as predicted by Hypothesis 1, but the effect is not significant for females. In addition, females bid significantly less when paired with an L than when paired with an H, in sharp contrast to Hypothesis 2, while the opposite is observed for males, in line with Hypothesis 2, although not significantly so.

These results explain why, as shown in the left panel of Figs. 2 and 3, the highest (lowest) bid levels are observed in *LL* and *LH* (*HH* and *HL*) pairs among males while, among females, the highest (lowest) bid levels are observed in *LH* and *HH* (*LL* and *HL*) pairs.

Thus, aggressive bidding is most commonly displayed by L types in both genders, but in different conditions: whereas for males maximal individual overbidding occurs in the condition in which two L compete ($M_{LL} = 83.63$), for females it occurs when an L competes against an H ($F_{LH} = 88.16$). Indeed, among males, the only significant difference between pair types is observed between *LL* and *HH* ($M_{LL} = 83.63$, $M_{HH} = 61.26$, $p = 0.05$, all remaining comparisons yield $p > 0.16$; Wald tests on the interaction coefficients in column 2, Table 3; similar results are obtained from columns 4 and 6). In the case of females, bids are significantly higher in condition *LH* compared to both *LL* ($F_{LH} = 88.16$, $F_{LL} = 66.26$, $p = 0.04$; Wald test on the interaction coefficients in column 2, Table 4) and *HL* ($F_{HL} = 69.88$, $p < 0.001$); all remaining comparisons yield $p > 0.18$. When the bids and outcomes from the previous period are accounted for, the results barely change. Thus, regarding bidding behavior, we have shown that,

*For males:* LL > HH and LØ > HØ. Hence L-types are more aggressive *irrespectively of the composition* of the pair (regarding FT).

*For females:* LH > HL, LH > LL; hence L-types behave more aggressively in front of H-types (mixed pairs) but not when they are

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[8] This difference does not reach significance when considering only the first period although the coefficient is identical (coeff=13.4, $p=0.17$; OLS), probably due to a lack of statistical power.

[9] Although our experiment was not designed to analyze males and females together, we checked the same regression using the whole sample and controlling for gender. The effect of own DR type is positive but not significant (coeff=6.132, $p=0.15$).

[10] Note that, for males, running regression (1) with the sample of regression 5 (people without missing values in controls) yields coeff=14.14, $p=0.03$ for *LØ* (vs *HØ*) and coeff=9.196, $p=0.16$ for *ØL* (vs *ØH*), whereas regression (3) using the sample of regression 5 yields coeff=10.754, $p=0.04$ for *LØ* (vs *HØ*) and coeff= 5.418, $p=0.30$ for *ØL* (vs *ØH*). For females, regression (1) using the sample of regression 5 yields coeff= 4.105, $p=0.47$ for *LØ* (vs *HØ*) and coeff= −16.808, $p<0.01$ for *ØL* (vs *ØH*), whereas regression (3) using the sample of regression 5 yields coeff= 4.602, $p=0.30$ for *LØ* (vs *HØ*) and coeff= −14.045, $p<0.01$ for *ØL* (vs *ØH*). Thus, the different samples result in similar estimates.

**Table 3**
Individual bids as a function of DR types (males).

| Dep var: *bid$_t$* | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| *LØ* (vs *HØ*) | 13.408* | 12.137 | 10.754* | 9.185 | 12.197* | 5.276 |
| | (6.269) | (9.816) | (5.139) | (7.795) | (5.108) | (7.043) |
| *ØL* (vs *ØH*) | 8.814 | 7.543 | 6.242 | 4.673 | 4.200 | −3.043 |
| | (6.269) | (9.816) | (5.141) | (7.796) | (5.049) | (7.085) |
| *LØ x ØL* | | 2.688 | | 3.318 | | 14.351 |
| | | (15.979) | | (12.417) | | (10.309) |
| *bid$_{t-1}$* | | | 0.185*** | 0.185*** | 0.204*** | 0.205*** |
| | | | (0.033) | (0.033) | (0.036) | (0.036) |
| *partner bid$_{t-1}$* | | | 0.082* | 0.082* | 0.118** | 0.121*** |
| | | | (0.033) | (0.033) | (0.036) | (0.036) |
| *win prize$_{t-1}$* | | | −5.597* | −5.595* | −6.737* | −6.746* |
| | | | (2.652) | (2.652) | (2.972) | (2.973) |
| *age* | | | | | −0.270 | −0.188 |
| | | | | | (0.501) | (0.498) |
| *intuitive* | | | | | 11.641 | 11.005 |
| | | | | | (6.004) | (5.945) |
| *risky* | | | | | −2.738 | −4.441 |
| | | | | | (5.146) | (5.143) |
| *BMI* | | | | | −0.674 | −0.838 |
| | | | | | (0.798) | (0.796) |
| *period* | 0.326 | 0.326 | 0.034 | 0.034 | −0.085 | −0.086 |
| | (0.267) | (0.267) | (0.292) | (0.292) | (0.326) | (0.326) |
| *Constant* | 58.069*** | 58.653*** | 47.286*** | 48.004*** | 64.048** | 70.108** |
| | (6.929) | (7.748) | (6.382) | (6.937) | (21.296) | (21.490) |
| *chi$^2$* | 6.107 | 6.139 | 49.591*** | 49.737*** | 74.008*** | 80.645*** |
| *N* | 1050 | 1050 | 980 | 980 | 812 | 812 |
| *N (indiv)* | 70 | 70 | 70 | 70 | 58 | 58 |
| *N (pairs)* | 35 | 35 | 35 | 35 | 34 | 34 |

**Note:** Estimates from mixed-effects GLMM with random effects clustered at the pair and individual levels to control for the nested nature of the data: *LØ* = 1 if the decision maker is L, = 0 if H, regardless of the opponent's DR type; *ØL* = 1 if he is playing against an L, = 0 if H, regardless of his own DR type; *intuitive* = 1 if above median # of intuitive responses in the CRT; *risky* = 1 if above median in preferences for risk; *BMI* = body mass index. Standard errors are presented in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

matched together. Also ØH > ØL, which means that any bidder (L or H) behave less aggressively in front of L-types.

As a main result we conclude:

**Result 1**. (*(bidding):*) *Males act primarily according to their own type (L is more aggressive than H) and respond weakly to their opponent's type. In contrast, females (re)act primarily according their opponent's type (H face more aggressive behavior than L) and weakly according to their own type.*

Taken together, we find support for Hypothesis 1 for males. Regarding Hypothesis 2, we find weak, non-significant support for males, whereas the results go in the opposite direction for females.

### *4.3. Payoff outcomes*

In this subsection we investigate how these differences in bidding behavior translate into outcomes. Note that due to the all-pay nature of the game, a higher effort from both players will result in lower payoffs for both, and vice versa when both spend less effort. The results should be mixed when one of them spends higher effort than the other. Figs. 4 and 5 show the dynamics of the decision makers' (realized) payoffs, respectively for males and females, using the same format of Figs. 2 and 3.

Contrary to the bidding results in the previous subsection, the opponent's type is the main driver of males' earnings (bottom right panel in Fig. 4), whereas the decision maker's type is the main driver of females' earnings (top right panel in Fig. 5). The regressions presented in columns 1 (males) and 3 (females) of Table 5 indeed corroborate these observations (i.e., only controlling for period; note that controlling for the decision maker's characteristics beyond type makes no sense here given that payoffs depend on both players' behavior).

The average payoffs of L and H males do not differ much ($M_{LØ}$=198.73, $M_{HØ}$=197.00, $p = 0.73$) but males earn significantly less when matched with L compared to H opponents ($M_{ØL} = 183.65$, $M_{ØH} = 210.46$, $p < 0.001$). L females, on the other hand, earn non-significantly more than H females ($F_{LØ}$=198.83, $F_{HØ}$=186.89, $p = 0.10$); the opponent's type does not affect females' payoffs ($F_{ØL} = 194.70$, $F_{ØH} = 190.41$, $p = 0.98$). Moreover, the interaction between the decision maker's type and the opponent's type (LØ x ØL) is non-significant for both males ($p = 0.73$, column 2) and females ($p = 0.60$, column 4).

In sum, DR relates differently to payoffs across genders: males earn less against L opponents (compared to against H), whereas L females earn more than H females, albeit non-significantly so.

As can be seen from the left panel of Figs. 4 and 5, the above effects result in males' payoffs being highest (lowest) in conditions *LH*

**Table 4**
Individual bids as a function of DR types (females).

| Dep var: $bid_t$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| *LØ* (vs *HØ)* | 2.840 | 8.816 | 3.731 | 8.426 | 2.723 | 4.729 |
| | (5.612) | (10.020) | (4.417) | (7.503) | (4.619) | (7.938) |
| *ØL* (vs *ØH)* | −15.440** | −9.464 | −13.107** | −8.413 | −13.393** | −11.441 |
| | (5.612) | (10.020) | (4.417) | (7.503) | (4.469) | (7.736) |
| *LØ X ØL* | | −12.441 | | −9.772 | | −4.070 |
| | | (17.325) | | (12.687) | | (13.166) |
| $bid_{t-1}$ | | | 0.226*** | 0.226*** | 0.231*** | 0.231*** |
| | | | (0.031) | (0.031) | (0.032) | (0.032) |
| *partner* $bid_{t-1}$ | | | 0.089** | 0.089** | 0.082** | 0.082** |
| | | | (0.031) | (0.031) | (0.031) | (0.031) |
| *win* $prize_{t-1}$ | | | −3.908 | −3.910 | −4.451 | −4.448 |
| | | | (2.279) | (2.279) | (2.293) | (2.293) |
| *age* | | | | | −0.524 | −0.502 |
| | | | | | (0.457) | (0.463) |
| *intuitive* | | | | | 3.334 | 3.290 |
| | | | | | (3.248) | (3.254) |
| *risky* | | | | | 3.436 | 3.258 |
| | | | | | (4.414) | (4.444) |
| *BMI* | | | | | −0.781 | −0.773 |
| | | | | | (0.576) | (0.577) |
| *period* | 0.063 | 0.063 | −0.235 | −0.235 | −0.232 | −0.232 |
| | (0.240) | (0.240) | (0.259) | (0.259) | (0.261) | (0.261) |
| *Constant* | 80.639*** | 78.846*** | 60.611*** | 59.200*** | 87.466*** | 86.260*** |
| | (6.420) | (6.851) | (6.117) | (6.319) | (16.055) | (16.477) |
| $chi^2$ | 14.150** | 14.688** | 85.556*** | 86.813*** | 97.637*** | 97.833*** |
| *N* | 1110 | 1110 | 1036 | 1036 | 1022 | 1022 |
| *N (indiv)* | 74 | 74 | 74 | 74 | 73 | 73 |
| *N (pairs)* | 37 | 37 | 37 | 37 | 37 | 37 |

**Note:** Estimates from mixed-effects GLMM with random effects clustered at the pair and individual levels to control for the nested nature of the data. See notes on Table 3 for a description of the variables used. Standard errors are presented in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

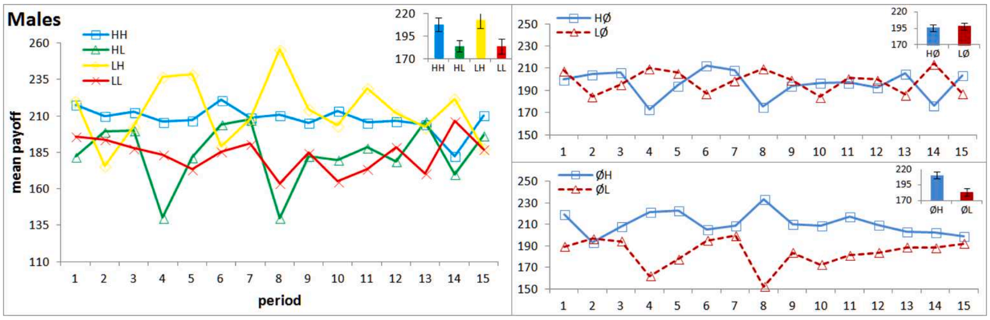

**Fig. 4.** Dynamics of mean payoffs: Males, **Note:** Top right panel compares payoffs of L (LØ) vs H (HØ) decision makers. Bottom right panel compares payoffs when the decision maker's opponent is L (ØL) vs H (ØH). Left panel shows payoffs across the four matching. Small embedded figures show mean payoffs collapsed across periods (error bars display SEM clustered at the pair level).

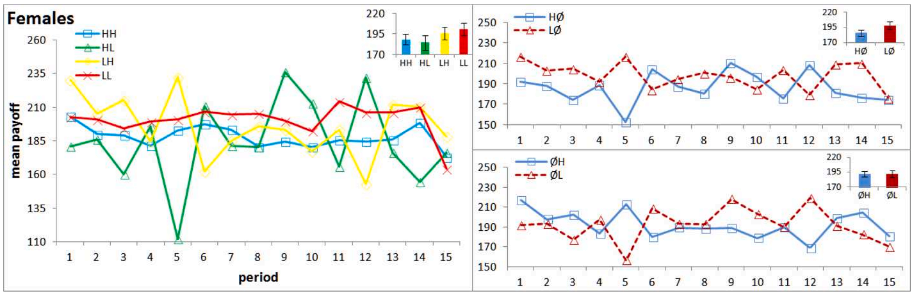

**Fig. 5.** Dynamics of mean payoffs: Females, **Note:** See notes in Fig. 4.

**Table 5**
Realized payoffs as a function of DR types: Males and females.

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Dep var: *payoff$_t$* | *males* | *males* | *females* | *females* | |
| *LØ* (vs *HØ*) | | 2.411 | 5.051 | 11.884 | 7.755 |
| | | (7.085) | (10.328) | (7.316) | (10.746) |
| *ØL* (vs *ØH*) | | −26.876*** | −24.237* | 0.165 | −3.964 |
| | | (7.085) | (10.328) | (7.316) | (10.746) |
| *LØ X ØL* | | | −5.582 | | 8.597 |
| | | | (15.907) | | (16.408) |
| *period* | | −0.363 | −0.363 | −0.593 | −0.593 |
| | | (0.615) | (0.615) | (0.617) | (0.617) |
| *Constant* | | 212.254*** | 211.041*** | 191.583*** | 192.822*** |
| | | (8.209) | (8.899) | (7.604) | (7.948) |
| *chi$^2$* | | 16.282*** | 16.422** | 3.657 | 3.944 |
| *N* | | 1050 | 1050 | 1110 | 1110 |
| *N (indiv)* | | 70 | 70 | 74 | 74 |
| *N (pairs)* | | 35 | 35 | 37 | 37 |

**Note:** Estimates from mixed-effects GLMM with random effects clustered at the pair and individual levels to control for the nested nature of the data. Standard errors are presented in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

and *HH* (*LL* and *HL*) while females' highest (lowest) payoffs are observed in conditions *LL* and *LH* (*HL* and *HH*). Thus, among males, the highly competitive environment of condition *LL* is associated with the lowest payoffs for both players ($M_{LL} = 183.37$), very similar to that obtained by H-types when paired with L-types ($M_{HL} = 183.90$, $p = 0.96$; Wald test on the interaction coefficients in column 2 of Table 5). In order to get high payoffs, both L and H males must be paired with H-types ($M_{LH} = 213.19$, $M_{HH} = 208.14$, which do not differ, $p = 0.63$, and both yield higher earnings than *LL* and *HL*, all $p < 0.03$). On the other hand, given that there is no escalation of conflict between L females in condition *LL*, the payoffs in this condition are the highest ($F_{LL} = 200.47$) and similar to those obtained by L females when paired with H-types ($F_{LH} = 195.84$). H females get low payoffs, irrespective of whether they are paired with L-types ($F_{HL} = 184.12$) or H-types ($F_{HH} = 188.08$). However, none of the pairwise comparisons between conditions reach significance for females (all $p > 0.14$; Wald tests on the interaction coefficients in column 4 of Table 5).

Thus, regarding payoffs, we have shown that,

*For males:* HH > HL, HH > LL, LH > HL, LH > LL and ØH > ØL. Earnings are lower when subjects are matched with L-types.

*For females:* No robust differences arise.

As a main result, we conclude:

**Result 2.** (*(bids + payoffs):*) *L-type males make the contest more aggressive (Result 1) and consequently they do not earn high payoffs. Instead, they make their counterparts to earn less. L-type females face less aggressive bids (Result 1) than H-type females, but DR types cause no impact on earnings.*

### 4.4. Power analysis

Clearly, the small sample size of our experiment limits the scope of the results. In this regard, please note that the final number of observations was not our choice but was instead the result of the design protocol, limited by the initial sample of DR measurements and the posterior attrition. Therefore, any power analysis could only be performed ex-post. To do so, we follow the procedure suggested by Gelman and Carlin (2014) using their *RETRODESIGN* command (for STATA, Linden 2019). This method yields three results for each test: power, type-S (sign) error, and type-M (magnitude) error. Power refers to the probability that the statistical test correctly rejects the null hypothesis, type-S error refers to the probability of the sign being in the opposite direction of the true effect, whereas type-M is the factor by which the magnitude of the effect size might be exaggerated (e.g., type-M error = 1.1 entails a 10 % exaggeration).

As is standard in power analyses, the crucial element is the true effect, which the researcher typically does not know. Following Gelman and Carlin (2014), we define different effect sizes and see how power, type-S and type-M errors vary with those changes. In particular, we define values about 10 % of the SD of bids (which varies between 40 and 45 depending on gender), 20 % of the SD of bids, and 50 % of bids, to which we add the observed effect (which for the current significant main results typically falls between the latter two values). Thus, we do the calculations for true effects of 4, 8, 20, and the observed effect.

In the case of males, for Hypothesis 1, we find that a significant difference between L and H decision makers would have power = 0.095, type-S error = 0.055, and type-M error = 3.839 if the true effect were equal to 4; the figures would be 0.238, 0.004, and 2.034 if the true effect were equal to 8; while they would be 0.882, 0.000, and 1.070 if the true effect were equal to 20. If the true effect were identical to the observed effect (i.e., 13.408), then power = 0.557, type-S error = 0.000, and type-M error = 1.337. Thus, in most of the cases, even if power is low, the probability that the effect goes in the opposite direction is below 5 %, yet the magnitude of the effect is likely exaggerated (see type-M errors). This suggests that it is very unlikely that the true effect is of opposite sign (i.e., H males bidding more than L males). Similarly applies to Hypothesis 2, for which the observed effect of the partner's type is 8.814 but not significant (power = 0.279, type-S error = 0.002, type-M error = 1.856). In the case of females, for true effects of 4, 8, and 20 we find power = 0.106, 0.286, and 0.940, respectively; type-S error = 0.040, 0.002, and 0.000; type-M error = 3.469, 1.848, and 1.039. The observed difference between L and H female decision makers is 2.840 and is not significant (Hypothesis 1); if that were the true effect, then power = 0.078, type-S error = 0.094, and type-M error = 4.836. The observed effect for the partner's type among females is 15.440; if that were the true effect, then power = 0.774, type-S error = 0.000, and type-M error = 1.144. Again, the significant effect observed for the partner's type on females' bids is unlikely to be of opposite sign as the true effect but is likely exaggerated.

The same analysis applied to the comparison between individual conditions (*HH, HL, LH, LL*) yields of course less power due to the smaller number of observations in each case. In fact, our hypotheses did not consider these comparisons but only the effect of the decision maker's and the opponents' type. We only provide such comparisons for completeness but are more likely to be underpowered.

## 5. Discussion

There is a distinct area of literature that investigates the effects of biological factors on economic decision making. One of such factors is the prenatal exposure to testosterone, and the existing literature has found mixed results. Whereas some studies have found significant effects of the prenatal exposure to testosterone on behavior, some other studies find null results. Very few studies, however, investigated the effects on competitive settings in a controlled manner and we contribute to this area.

Specifically, we provide controlled evidence that dyadic competition yields very different outcomes depending on the FT 'types' of those interacting. One of the potential confounding factors that our study controls for is ability: ruling out the explanation that differences in behavior and outcomes are driven by differences in (unobservable) ability that correlate with FT exposure. We extend the literature on how FT relates to individuals' behavior and outcomes in competitive settings such as sports, financial trading, and entrepreneurship (Bennett et al., 2010; Manning and Taylor, 2001; Nicolaou et al., 2018; Sapienza et al., 2009). In addition, our experiment imposes a competitive environment which cannot be avoided by the individual. Furthermore, our study is the first to perform a controlled match of different FT (DR) types. These two features of the design alleviate confounding factors related, for example, to self-selection issues.

We find that L-type males (i.e., those more exposed to FT according to our DR proxy) spend higher effort, but do not earn more than H-type males. Anybody matched with L-type males earns less than when matched with H-type males. In addition, all females exert more effort against H-types, but this does not translate robustly into payoffs. Hence, our main result thus shows that males act primarily according to their own type and react weakly to their opponent's type while, in sharp contrast, females (re)act primarily according to their opponent's type and weakly according to their own type. Although gender differences in attitudes toward competition have been documented before (e.g., Niederle and Vesterlund, 2007), we set up an environment in which competition cannot be avoided. Therefore, once individuals are exogenously introduced in a competitive situation, our findings suggest that prenatal factors matter for both genders, but males and females have a fundamentally different approach to dyadic competition. The results give considerable support to Hypothesis 1 stating that higher FT exposure should result in more aggressive conflict behavior, although only among males. Hypothesis 2, which holds that L-types should face larger conflict effort by the opponent than H-types, finds weak non-significant support for males, but the results go *against* Hypothesis 2 for females. As our ex-post power analyses suggest, it is very unlikely that the true effect goes in the opposite direction of the observed effects, yet the observed effect sizes are likely exaggerated. Future studies using larger samples should therefore confirm our results; note that this is the first time a causal mechanism is implemented in the DR-behavior literature in humans, which we hope stimulates further research using similar methodologies.

Interestingly, our main result may be related to Croson and Gneezy's (2009) observation that females' behavior is more context dependent (where context here means the opponent's type). Our finding that females react according to their opponent's type, in turn, can explain some of the existing observations in the literature such that: females reacting more than males in identity related conflict (Chowdhury et al., 2016), or females exerting more effort against other females, but males not reacting to gender (Mago and Razzolini, 2019). However, our regression analysis suggests that female players (also) take into consideration factors other than the opponent's behavior in the previous period, as a continuous variable. Further research should explore this result in greater detail since we do not have enough power to run more exploratory analyses. Therefore, this result should be interpreted with caution until more data are gathered.

Our findings may help explain outcomes in certain professional settings, especially those dominated by a single gender and/or favored by certain FT types. Financial trading and professional sports, two male-dominated professions that disproportionately attract L-types (Manning and Taylor, 2001; Sapienza et al., 2009), would be predicted to feature aggressive competition for a win, for example. This prediction is in line with anecdotal evidence, as well as reports of cases where a "win at all costs" mentality has led some competitors to breaking rules. Because we find that L-type males compete more fiercely than H-type males, this may explain why L-type males are more likely to prevail in certain settings.

The relationship between prenatal development, competition, and conflict is a fruitful area for further research. Follow-up studies could look at wider consequences for society, for example by asking how FT affects group conflict and coalition formation as well as intergroup bias (Abbink et al., 2010; Espín et al., 2015), or how leveling the playing field (Chowdhury et al., 2023) and sabotage behavior (Chowdhury and Gürtler, 2015) can be affected. More generally, it will be important to consider how biological factors affect behavior in common social settings, such as networks and organizations.

## 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.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.joep.2023.102623.

## References

Abbink, K., Brandts, J., Herrmann, B., & Orzen, H. (2010). Intergroup conflict and intra-group punishment in an experimental contest game. *The American Economic Review, 100*(1), 420–447.

Arnold, A. P., & Breedlove, S. M. (1985). Organizational and activational effects of sex steroids on brain and behavior: A reanalysis. *Hormones and Behavior, 19*(4), 469–498.

Bailey, A. A., & Hurd, P. L. (2005). Finger length ratio (2D: 4D) correlates with physical aggression in men but not in women. *Biological Psychology, 68*(3), 215–222.

Bao, A. M., & Swaab, D. F. (2011). Sexual differentiation of the human brain: Relation to gender identity, sexual orientation and neuropsychiatric disorders. *Frontiers in Neuroendocrinology, 32*(2), 214–226.

Benderlioglu, Z., & Nelson, R. J. (2004). Digit length ratios predict reactive aggression in women, but not in men. *Hormones and Behavior, 46*(5), 558–564.

Bennett, M., Manning, J. T., Cook, C. J., & Kilduff, L. P. (2010). Digit ratio (2D: 4D) and performance in elite rugby players. *Journal of Sports Sciences, 28*(13), 1415–1421.

Berenbaum, S. A., Bryk, K. K., Nowak, N., Quigley, C. A., & Moffat, S. (2009). Fingers as a marker of prenatal androgen exposure. *Endocrinology, 150*(11), 5119–5124.

Bönte, W., Procher, V. D., & Urbig, D. (2016). Biology and selection into entrepreneurship—The relevance of prenatal testosterone exposure. *Entrepreneurship Theory and Practice, 40*(5), 1121–1148.

Bönte, W., Procher, V. D., Urbig, D., & Voracek, M. (2017). Digit Ratio (2D: 4D) Predicts Self-Reported Measures of General Competitiveness, but Not Behavior in Economic Experiments. *Frontiers in Behavioral Neuroscience, 11*, 238.

Booth, A., Shelley, G., Mazur, A., Tharp, G., & Kittok, R. (1989). Testosterone, and winning and losing in human competition. *Hormones and behavior, 23*(4), 556–571.

Bosch-Domènech, A., Brañas-Garza, P., & Espín, A. M. (2014). Can exposure to prenatal sex hormones (2D: 4D) predict cognitive reflection? *Psychoneuroendocrinology, 43*, 1–10.

Brañas-Garza, P., Galizzi, M. M., & Nieboer, J. (2018). Experimental and self-reported measures of risk taking and digit ratio (2D:4D): Evidence from a large, systematic study. *International Economic Review, 59*(3), 1131–1157.

Brown, W. M., Hines, M., Fane, B. A., & Breedlove, S. M. (2002). Masculinized finger length patterns in human males and females with congenital adrenal hyperplasia. *Hormones and Behavior, 42*(4), 380–386.

Butovskaya, M., Burkova, V., Apalkova, Y., Dronova, D., Rostovtseva, V., Karelin, D., … Batsevich, V. (2021). Sex, population origin, age and average digit length as predictors of digit ratio in three large world populations. *Scientific Reports, 11*(1), 1–17.

Cecchi, F., & Duchoslav, I. (2018). The Effect of Prenatal Stress on Cooperation: Evidence from Violent Conflict in Uganda. *European Economic Review, 101*(1), 35–56.

Charness, G., Masclet, D., & Villeval, M. C. (2014). The dark side of competition for status. *Management Science, 60*(1), 38–55.

Chowdhury, S. M., Esteve-González, P., & Mukherjee, A. (2023). Heterogeneity, leveling the playing field, and affirmative action in contests. *Southern Economic Journal, 89*(3), 924–974.

Chowdhury, S. M., & Gürtler, O. (2015). Sabotage in contests: A survey. *Public Choice, 164*, 135–155.

Chowdhury, S. M., Jeon, J. Y., & Ramalingam, A. (2016). Identity and group conflict. *European Economic Review, 90*, 107–121.

Chowdhury, S. M., Jeon, J. Y., & Ramalingam, A. (2018). Property Rights and Loss-aversion in Contests. *Economic Inquiry, 56*(3), 1492–1511.

Chowdhury, S. M., Mukherjee, A., & Turocy, T. (2020). That's the Ticket: Explicit Lottery Randomisation and Learning in Tullock Contests. *Theory and Decision, 88*(3), 405–429.

Chowdhury, S. M., & Sheremeta, R. M. (2011). Multiple equilibria in Tullock contests. *Economics Letters, 112*(2), 216–219.

Chowdhury, S. M., Sheremeta, R. M., & Turocy, T. (2014). Overbidding and Overspreading in Rent-seeking Experiments: Cost Structure and Prize Allocation Rules. *Games and Economic Behavior, 87*, 224–238.

Coates, J. M., & Herbert, J. (2008). Endogenous steroids and financial risk taking on a London trading floor. *Proceedings of the National Academy of Sciences, 105*, 6167–6172.

Coates, J. M., Gurnell, M., & Rustichini, A. (2009). Second-to-fourth digit ratio predicts success among high-frequency financial traders. *Proceedings of the National Academy of Sciences, 106*(2), 623–628.

Coates, J. M., Gurnell, M., & Sarnyai, Z. (2010). From molecule to market: Steroid hormones and financial risk-taking. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*, 331–343.

Cronqvist, H., Previtero, A., Siegel, S., & White, R. T. (2016). The fetal origins hypothesis in finance: Prenatal environment, financial risk taking. *Review of Financial Studies, 29*, 739–786.

Croson, R., & Gneezy, U. (2009). Gender Differences in Preferences. *Journal of Economic Literature, 47*(2), 448–474.

Dabbs, J. M., & Dabbs, M. G. (2000). *Heroes, rogues, and lovers.* Testosterone and behavior. McGraw-Hill.

Datta Gupta, N., Poulsen, A., & Villeval, M. C. (2013). Gender matching and competitiveness: Experimental evidence. *Economic Inquiry, 51*(1), 816–835.

Dechenaux, E., Kovenock, D., & Sheremeta, R. M. (2015). A survey of experimental research on contests, all-pay auctions and tournaments. *Experimental Economics, 18*(4), 609–669.

Espín, A. M., Exadaktylos, F., Herrmann, B., & Brañas-Garza, P. (2015). Short-and long-run goals in ultimatum bargaining: Impatience predicts spite-based behavior. *Frontiers in Behavioral Neuroscience, 9*, 214.

Finegan, J. K., Bartleman, B., & Wong, P. Y. (1989). A window for the study of prenatal sex hormone influences on postnatal development. *Journal of Genetic Psychology, 150*, 101–112.

Fink, B., Neave, N., & Manning, J. T. (2003). Second to fourth digit ratio, body mass index, waist-to-hip ratio, and waist-to-chest ratio: Their relationships in heterosexual men and women. *Annals of Human Biology, 30*(6), 728–738.

Finley, B., Kalwij, A., & Kapteyn, A. (2022). Born to be wild: Second-to-fourth digit length ratio and risk preferences. *Economics & Human Biology, 47*, Article 101178.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-made Economic Experiments. *Experimental Economics, 10*(2), 171–178.

Fossen, F. M., Neyse, L., Johannesson, M., & Dreber, A. (2021). 2D: 4D and Self-Employment: A Preregistered Replication Study in a Large General Population Sample. *Entrepreneurship Theory and Practice*, 1042258720985478.

Galis, F., Ten Broek, C. M. A., Van Dongen, S., & Wijnaendts, L. C. D. (2010). Sexual Dimorphism in the Prenatal Digit Ratio (2D:4D). *Archives of Sexual Behavior, 39*(1), 57–62.

Galizzi, M. M., & Nieboer, J. (2015). Digit ratio (2D:4D) and altruism: Evidence from a large, multi-ethnic sample. *Frontiers in Behavioral Neuroscience, 23*, 41.

Garn, S. M., Burdi, A. R., Babler, W. J., & Stinson, S. (1975). Early prenatal attainment of adult metacarpal-phalangeal rankings and proportions. *American Journal of Physical Anthropology, 43*(3), 327–332.

Gelman, A., & Carlin, J. (2014). Beyond power calculations: Assessing type S (sign) and type M (magnitude) errors. *Perspectives on Psychological Science, 9*(6), 641–651.

Gomez-Mejia, L., Trevino, L. J., & Mixon, F. G., Jr (2009). Winning the tournament for named professorships in management. *The International Journal of Human Resource Management, 20*(9), 1843–1863.

Goy, R. W., & McEwen, B. S. (1980). *Sexual differentiation of the brain.* Cambridge, MA: MIT Press.

Herbert, J. (2015). *Testosterone: The molecule behind power, sex, and the will to win.* Oxford: Oxford University Press.

Herbert, J. (2018). Testosterone, Cortisol and Financial Risk-Taking. *Frontiers in Behavioral Neuroscience, 12*, 101.

Hilgard, J., Engelhardt, C. R., Rouder, J. N., Segert, I. L., & Bartholow, B. D. (2019). Null effects of game violence, game difficulty, and 2D: 4D digit ratio on aggressive behavior. *Psychological Science, 30*(4), 606–616.

Hines, M., Golombok, S., Rust, J., Johnston, K., Golding, J., & The ALSPAC Study Team. (2002). Testosterone during pregnancy and childhood gender role behavior: a longitudinal population study. *Child Development, 73*, 1678–1687.

Hines, M. (2006). Prenatal testosterone and gender-related behaviour. *European Journal of Endocrinology, 155*, 115–121.

Kim, T. B., Oh, J. K., Kim, K. T., Yoon, S. J., & Kim, S. W. (2015). Does the mother or father determine the offspring sex ratio? Investigating the relationship between maternal digit ratio and offspring sex ratio. *PLoS ONE, 10*(11), Article e0143054.

Konrad, K. A. (2009). *Strategy and Dynamics in Contest*. Oxford: Oxford University Press.

Leslie, M. (2019). The mismeasure of hands? *Science, 364*(6444), 923–925.

Linden, A. (2019). RETRODESIGN: Stata module to compute type-S (Sign) and type-M (Magnitude) errors. https://econpapers.repec.org/software/bocbocode/S458631.htm.

Lutchmaya, S., Baron-Cohen, S., Raggatt, P., Knickmeyer, R., & Manning, J. T. (2004). 2nd to 4th digit ratios, fetal testosterone and estradiol. *Early Human Development, 77*, 23–28.

Mago, S. D., & Razzolini, L. (2019). Best-of-five contest: An experiment on gender differences. *Journal of Economic Behavior & Organization, 162*, 164–187.

Malas, M. A., Dogan, S., Evcil, E. H., & Desdicioglu, K. (2006). Fetal development of the hand, digits and digits ratio (2D:4D). *Early Human Development, 82*, 469–475.

Manning, J. T., & Fink, B. (2008). Digit ratio (2D: 4D), dominance, reproductive success, asymmetry, and sociosexuality in the BBC Internet Study. *American Journal of Human Biology, 20*(4), 451–461.

Manning, J. T., & Fink, B. (2017). Are there any" direct" human studies of digit ratio (2D: 4D) and measures of prenatal sex hormones? *Early Human Development, 113*, 73–74.

Manning, J. T., Scutt, D., Wilson, J., & Lewis-Jones, D. I. (1998). The ratio of 2nd to 4th digit length: A predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. *Human Reproduction, 13*(11), 3000–3004.

Manning, J. T., & Taylor, R. P. (2001). Second to fourth digit ratio and male ability in sport: Implications for sexual selection in humans. *Evolution and Human Behavior, 22*(1), 61–69.

Manning, J. T., Kilduff, L. P., & Trivers, R. (2013). Digit ratio (2D:4D) in Klinefelter's syndrome. *Andrology, 1*(1), 94–99.

McIntyre, M. H., Ellison, P. T., Lieberman, D. E., Demerath, E., & Towne, B. (2005). The development of sex differences in digital formula from infancy in the Fels Longitudinal Study. *Proceedings of the Royal Society B: Biological Sciences, 272*(1571), 1473–1479.

Nave, G., Koppin, C. M., Manfredi, D., Richards, G., Watson, S. J., Geffner, M. E., Yong, J. E., Kim, R., Ross, H. M., Serrano-Gonzalez, M., & Kim, M. S. (2021). No evidence for a difference in 2D: 4D ratio between youth with elevated prenatal androgen exposure due to congenital adrenal hyperplasia and controls. *Hormones and Behavior, 128*, Article 104908.

Neave, N., Laing, S., Fink, B., & Manning, J. T. (2003). Second to fourth digit ratio, testosterone and perceived male dominance. *Proceedings of the Royal Society B: Biological Sciences, 270*(1529), 2167–2172.

Neyse, L., & Brañas-Garza, P. (2014). Digit Ratio Measurement Guide. *MPRA WPaper, 54134*.

Neyse, L., Johannesson, M., & Dreber, A. (2021). 2D: 4D does not predict economic preferences: Evidence from a large, representative sample. *Journal of Economic Behavior & Organization, 185*, 390–401.

Nicolaou, N., Patel, P. C., & Wolfe, M. T. (2018). Testosterone and tendency to engage in self-employment. *Management Science, 64*(4), 1825–1841.

Niederle, M., & Vesterlund, L. (2007). Do women shy away from competition? Do men compete too much? *The Quarterly Journal of Economics, 122*(3), 1067–1101.

Orrison, A., Schotter, A., & Weigelt, K. (2004). Multiperson tournaments: An experimental examination. *Management Science, 50*(2), 268–279.

Pearson, M., & Schipper, B. C. (2012). The Visible Hand: Finger ratio (2D: 4D) and competitive bidding. *Experimental Economics, 15*(3), 510–529.

Potters, J., De Vries, C. G., & Van Winden, F. (1998). An experimental examination of rational rent-seeking. *European Journal of Political Economy, 14*(4), 783–800.

Price, C. R., & Sheremeta, R. M. (2015). Endowment origin, demographic effects, and individual preferences in contests. *Journal of Economics & Management Strategy, 24*(3), 597–619.

Richards, G. (2017). What Is the Evidence for a Link Between Digit Ratio (2D: 4D) and Direct Measures of Prenatal Sex Hormones? *Early Human Development, 113*, 71–72.

Rodeck, C. H., Gill, D., Rosenberg, D. A., & Collins, W. P. (1985). Testosterone levels in midtrimester maternal and fetal plasma and amniotic fluid. *Prenatal Diagnosis, 5*, 175–181.

Sapienza, P., Zingales, L., & Maestripieri, D. (2009). Gender differences in financial risk aversion and career choices are affected by testosterone. *Proceedings of the National Academy of Sciences, 106*(36), 15268–15273.

Sheremeta, R. M. (2013). Overbidding and heterogeneous behavior in contest experiments. *Journal of Economic Surveys, 27*(3), 491–514.

Sheremeta, R. M. (2018). Impulsive behavior in competition: Testing theories of overbidding in rent-seeking contests. *Available at SSRN 2676419*.

Szidarovszky, F., & Okuguchi, K. (1997). On the existence and uniqueness of pure Nash equilibrium in rent-seeking games. *Games and Economic Behavior, 18*(1), 135–140.

Tester, N., & Campbell, A. (2007). Sporting achievement: What is the contribution of digit ratio? *Journal of Personality, 75*(4), 663–677.

Trivers, R., Manning, J. T., & Jacobson, A. (2006). A longitudinal study of digit ratio (2D: 4D) and other finger ratios in Jamaican children. *Hormones and Behavior, 49*(2), 150–156.

Tullock, G. (1980). Efficient Rent Seeking. In J. M. Buchanan, R. D. Tollison, & G. Tullock (Eds.), *Toward a Theory of the Rent-Seeking Society* (pp. 97–112). College Station, TX: Texas A&M University Press.

Turanovic, J. J., Pratt, T. C., & Piquero, A. R. (2017). Exposure to fetal testosterone, aggression, and violent behavior: A meta-analysis of the 2D: 4D digit ratio. *Aggression and Violent Behavior, 33*, 51–61.

Udry, J. R., Morris, N. M., & Kovenock, J. (1995). Androgen effects on women's gendered behaviour. *Journal of Biosocial Science, 27*(359–368), 22.

van Anders, S. M., Vernon, P. A., & Wilbur, C. J. (2006). Finger-length ratios show evidence of prenatal hormone-transfer between opposite-sex twins. *Hormones and Behavior, 49*(3), 315–319.

Van den Bergh, B., & Dewitte, S. (2006). Digit ratio (2D : 4D) moderates the impact of sexual cues on men's decisions in ultimatum games. *Proceedings of the Royal Society B: Biological Sciences, 273*(1597), 2091–2095.

Ventura, T., Gomes, M. C., Pita, A., Neto, M. T., & Taylor, A. (2013). Digit ratio (2D:4D) in newborns: Influences of prenatal testosterone and maternal environment. *Early Human Development, 89*(2), 107–112.