Second-to-fourth digit ratio predicts success among high-frequency financial traders

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Prenatal androgens have important organizing effects on brain development and future behavior. The second-to-fourth digit length ratio (2D:4D) has been proposed as a marker of these prenatal androgen effects, a relatively longer fourth finger indicating higher prenatal androgen exposure. 2D:4D has been shown to predict success in highly competitive sports. Yet, little is known about the effects of prenatal androgens on an economically influential class of competitive risk taking—trading in the financial world. Here, we report the findings of a study conducted in the City of London in which we sampled 2D:4D from a group of male traders engaged in what is variously called ''noise'' or ''high-frequency'' trading. We found that 2D:4D predicted the traders' long-term profitability as well as the number of years they remained in the business. 2D:4D also predicted the sensitivity of their profitability to increases both in circulating testosterone and in market volatility. Our results suggest that prenatal androgens increase risk preferences and promote more rapid visuomotor scanning and physical reflexes. The success and longevity of traders exposed to high levels of prenatal androgens further suggests that financial markets may select for biological traits rather than rational expectations.

2D:4D | neuro-economics | risk taking | market selection | testosterone

Successful trading in the financial markets requires more than correct beliefs about the value of securities. Traders must also possess confidence enough to place their bets, risk preferences high enough to place bets of meaningful size, and the ability to process information quickly enough to keep one step ahead of competitors. Furthermore, traders engaged in "noise" or "high-frequency" trading require additional skills because their rapid style of trading is a demanding physical activity: they engage in extended periods of vigilance and visuomotor scanning, and they must react quickly to place a trade before other traders arbitrage it away. The physiological demands made on traders raise the possibility that success in the markets depends as much on traders' biological traits as it does on the truth of their beliefs.

These biological traits may derive in part from traders' prenatal exposure to androgenic steroids. Prenatal androgens have organizing effects on the developing brain, increasing its later sensitivity to the activational effects of circulating testosterone (1–3). According to both animal and human studies, these effects may include increased confidence (4), risk preferences (5–7), and search persistence (8), as well as heightened vigilance and quickened reaction times (9). A number of surrogate markers have been proposed for measuring the effects of fetal androgens (10), but perhaps the most convenient is the second-to-fourth digit length ratio (2D:4D), a relatively longer fourth finger (i.e., lower 2D:4D) indicating higher fetal androgens (11). Digit ratios have been found to predict performance in competitive sports, such as soccer (12), rugby, basketball (13), and skiing (14), so 2D:4D may also predict the risk preferences and physical speed required for high-frequency trading. We therefore formulated the hypothesis that higher prenatal testosterone exposure would improve a trader's performance. Specifically, we predicted that traders with a lower 2D:4D would make greater long-term profits and would remain in the business for a longer period of time.

To test our prediction we recruited 49 male traders from a trading floor in the City of London (15). This floor employed ≈200 traders, of which all but 3 were male. The more successful of these traders earn in excess of £4 million per year. The floor is typical of others in the financial world with respect to its physical layout, the markets traded, and the traders' average age and income (Fig. 1). The traders on this floor specialize in noise or high-frequency trading: they buy and sell securities, specifically futures contracts, sometimes in sizes of up to £1 billion, but hold their positions for only a few minutes, sometimes mere seconds (16). Other types of traders, such as investors at mutual and pension funds or arbitrageurs at hedge funds and investment banks, take more time to analyze a security's value and hold their trades for weeks, months, or years. Investors and arbitrageurs try to profit from market trends, whereas high-frequency traders make their money by trading temporary variations around the trend.

We used individual traders' profit and loss (P&L) statements as the primary measure of their relative performance. Trader P&Ls are recorded continuously by the firm's back office, so they are free of reporting bias. Traders had equal access to capital and information, and their risk limits were determined by their track records. P&L for this cohort was thus an objective and comparable measure of trading skill and, after profit sharing with the employing firm, determined their individual income. These traders received no salary or year-end bonus, and their P&Ls did not have the benefits of an underlying client business. Consequently, selective pressures act more quickly and insistently on these traders than on investment bankers or fund managers.

For ease of measurement and reproducibility we used 2D:4D as a surrogate measure of prenatal androgen exposure. Support for this measure, according to some researchers, derives from the fact that digit growth and gonadal development are linked by the common influence of *hox* genes (11, 17). Members of the homeobox-containing gene family (e.g., *hoxa* and *hoxd*) are strongly expressed in the genital bud and give rise to the urogenital system; yet, they also pattern limb development and digit growth (18). Indeed, loss-of-function mutations in *HOXA13* result in both shortening of the digits and defects in the urogenital tract (hand–foot–genital syndrome) (19).

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A

B

	Age (years)	Trading experience (years)	Approximate Annual Income (£1~$2)
Mean	26.9	2.77	£285,000
Std	4.14	1.9	£59,000
Range	19 to 38	1 to 12	-£2,000 to £4,200,000

Fig. 1. The trading floor. (*A*) Trading desks are fitted with screens displaying live prices of bond, currency, comm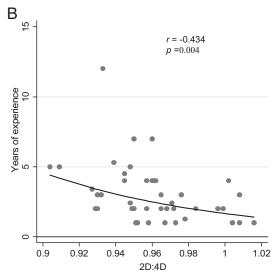odity, and stock index futures. The desks also include computerized risk management systems, live newsfeeds, and a ''squawk box'' over which an economist comments on the economic statistics being released in the major global markets. The traders can trade a range of futures contracts, but most confine their attention to European and predominantly German stock indices or interest rate contracts. Traders typically look for intraday peaks and troughs in futures prices or search the screens for small price discrepancies both within and between markets. These trading opportunities may present themselves for no more than a few seconds, so traders have little time for analysis. When searching the screens, traders display a focused attention and physical readiness, appearing much like a tennis player at net. (*B*) Summary statistics for traders in the study. Negative income denotes trading costs that exceed P&L.

Further evidence of a connection between digit ratios and prenatal androgens comes from the observation that 2D:4D is sexually dimorphic, with male ratios typically shorter than those of females. This dimorphism emerges in the first trimester of development (20) and is established in children by the age of 2 years (11). Clinical support for the measure comes from studies in which males and females with congenital adrenal hyperplasia, a condition that first manifests in utero and that leads to disrupted steroid biosynthesis and consequent overproduction of androgens, have been found to have lower right-hand 2D:4D (21, 22). Lower digit ratios also have been shown to correlate with increased sensitivity of the androgen receptor (and, hence, greater androgen action), as reflected by the CAG repeat length in the androgen receptor gene (23). Taken together, these findings suggest that sex steroids produced by the developing gonads exert important modulatory effects on digit growth (24).

To determine 2D:4D, we obtained photocopies of traders' right hands and measured digit length from the metacarpophalangeal crease to the finger tip (see *Materials and Methods*). This crease, the most proximal between finger and palm, appears around the ninth week of gestation and is one of the primary or regular creases of the hand—deep and permanent creases developing independently of finger movement and forming over joints and between digital and volar pads (25).

Results

According to our prediction, traders with a lower 2D:4D should make higher profits. Of the 49 traders originally recruited, 5 were

Fig. 2. 2D:4D vs. P&L and years of experience. (*A*) Plot of each trader's average monthly P&L (Box-Cox-transformed) correlated with his 2D:4D ratio. (*B*) Plot of each trader's years of trading experience correlated with his 2D:4D. The scatter plot displays raw data, but the fitted line is derived from a robust regression of 2D:4D on log-transformed years of experience. Years of experience were log-transformed because (*i*) years cannot be negative and (*ii*) the relationship between years and 2D:4D is exponential rather than linear.

subsequently excluded from the study (see *Materials and Methods*). For the remaining 44 traders we requested 20 months of P&L data from the bank. We first examined the correlation between 2D:4D and average monthly P&L. Like all income data, P&L is heavily skewed to the right, so we used a Box-Cox nonlinear transformation to normalize the data [see supporting information (SI)]. We found that the lower a trader's 2D:4D ratio, the greater his P&L ($n = 44, r = -0.482, P = 0.0009$; Fig. 2*A*). We also rank-ordered the P&L, and rank too showed a significant correlation with digit ratio ($n = 44, r = 0.492, P = 0.0007$).

We next looked at 2 other variables that may affect a trader's performance—age and years of trading experience. Trading experience affects P&L in a nonlinear fashion: P&L rises sharply in the first 2 years of trading as beginners learn the basics and develop their own trading style; for the next 10 years or so,

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Table 1. Average annual income by class of 2D:4D and experience (£ ≈ $2)

2D:4D	Experience		
	Inexperienced (≤2 yr)	Experienced (>2 yr)	Average
Low (0.932)	£145,080	£828,480	£679,680
Medium (0.956)	£62,400	£299,880	£173,160
High (0.988)	£27,360	£154,440	£61,320
Average (0.959)	£56,160	£537,720	£296,880

2D:4D is grouped by tertile, with the average digit ratio in parentheses. Experience is grouped by number of years trading, with inexperienced traders defined as anyone trading for 2 years or less.

traders on this floor perform at their peak, and P&L on average remains relatively constant (see SI). Therefore, we estimated the effect of experience with a dummy variable equal to zero for traders who had traded 2 years or less and to one for all others. We regressed P&L on age, experience, and 2D:4D. Age and 2D:4D were normalized to have a unit range, permitting the estimated coefficients to be compared to that of experience. The resulting model displayed good explanatory power ($R^2 = 0.553$) and was significant ($F_{3,40} = 20.26$, $P < 0.00005$); age was not significant ($P = 0.163$), but the experience variable was ($b = 0.98$, $P = 0.00003$); and 2D:4D was also highly significant ($b = -1.21$, $P = 0.0008$). Accordingly, age was omitted from subsequent analyses, leaving us with a simple 2-factor model with 1 variable each from biology and experience—the former represented by 2D:4D and the latter by years of training.

Finally, to control for possible confounding effects on the P&L data of some traders having overlapping but not identical sampling dates, we examined a subgroup of 25 traders who shared the same 20 months of P&L. Regressing P&L on experience and 2D:4D for these subjects revealed results similar to those reported above ($R^2 = 0.53$, $F_{3,21} = 9.35$, $P < 0.0005$): experience ($b = 0.94$, $P = 0.0007$) and 2D:4D ($b = -1.40$, $P = 0.002$). As an alternative method, one that makes use of the full sample size of 44 subjects, we used panel data and added time dummy variables for each 3-month interval in the sampling period. This model too showed significant results ($R^2 = 0.505$, $P < 0.0005$) (SI): the coefficients experience ($b = 0.994$, $P < 0.0005$) and 2D:4D ($b = -1.031$, $P = 0.004$) were highly significant. Taken together, these results suggest that 2D:4D predicts a high-frequency trader's long-term profitability.

The coefficients of our independent variables showed an approximate equal contribution of 2D:4D and experience to an individual trader's profitability. However, interpretation of the P&L coefficient is complicated because the P&L data have undergone a Box-Cox transformation. If we look instead at raw data, we find that an experienced trader makes, on average, 9.6 times the P&L of an inexperienced one, and a trader in the lowest tertile of the 2D:4D range makes 11 times the P&L of a trader in the highest tertile (Table 1). If we consider experienced traders only, we find that low 2D:4D traders make, on average, 5.4 times the P&L of high 2D:4D traders.
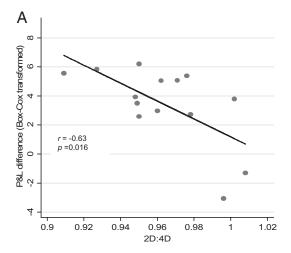
In light of these findings, we considered the possibility that low-2D:4D traders take the greatest risks, are profitable for a while, but ultimately suffer losses great enough to remove them from the markets. However, this was not the case: there was no tendency for low-2D:4D traders to be selected against. In fact, quite the opposite was true. When we plotted a trader's 2D:4D against his years of trading experience, we observed that the lower a trader's digit ratio, the greater the number of years he had traded ($n = 44$, $r = -0.43$, $P = 0.004$; Fig. 2B). Our data did not, however, allow us to determine why low-2D:4D traders

remain in the business longer than others, nor whether their decision to remain stems from their ability or their motivation.

Can we explain why 2D:4D predicts a trader's P&L? To address this important question, we undertook 2 further analyses. First, prenatal androgens, as reflected in 2D:4D, may have the organizing effect of sensitizing a trader's body and brain to the later effects of circulating testosterone (1–3, 26). According to the organizational/activational model of steroid action, sex steroids acting during prenatal development permanently alter neural substrates in such a way as to make them, and hence behavior, more susceptible to the later activational effects of the circulating steroid (27). Therefore, to understand how androgens influence human or animal behavior, one ideally requires measures of both prenatal and postnatal androgen action (28, 29). We were able to study surrogates of both of these measures for a subgroup of subjects in our sample population. Seventeen of our traders participated in a separate study in which salivary steroid levels were measured (30). In that study we noted that on days when traders had high morning testosterone compared with their median level during the study, they recorded a significantly higher P&L for the rest of that day than they did on days of low morning testosterone. In other words, morning testosterone levels predicted afternoon P&L. The difference in the trader's P&L between days of high and low testosterone (let us call this measure "P&L difference") could therefore be taken as a measure of the sensitivity of his trading performance to changes in circulating testosterone. Consequently, we examined whether 2D:4D predicted the magnitude of the trader's P&L difference.

A total of 3 of the 17 traders had already been excluded from the current study because they had broken either the index or ring finger of their right hand. For the remaining 14 traders, we found that 2D:4D predicted the magnitude of the P&L difference ($n = 14$, $r = -0.63$, $P = 0.016$; Fig. 3A). We also regressed the P&L difference against both experience and 2D:4D: the regression displayed significance ($R^2 = 0.41$, $F_{2,11} = 13.17$, $P = 0.0012$), as did the explanatory variables, experience ($P = 0.007$) and 2D:4D ($P = 0.032$). This result suggests that prenatal androgen exposure may affect a trader by sensitizing his subsequent trading performance to changes in circulating testosterone. Previous studies have found that elevated levels of testosterone or enhanced androgen action can increase confidence (4) and risk preferences (5–7), and these effects would augment the P&L of any trader with a positive expected return.

Our second line of analysis looked at the possibility that 2D:4D predicts traits that increase the return of traders engaged specifically in noise or high-frequency trading. This form of trading demands intense attention, involves lengthy periods of visuomotor scanning, and requires rapid cognitive and physical reflexes. To test the prediction that 2D:4D correlates with speed of cognitive processing and physical reactions, we examined how traders performed when the volatility of the market—i.e., the frequency and amplitude of price changes—increased. As volatility rises, more opportunities for making money present themselves, but they occur more quickly, permitting traders less time for decision making. Previous studies have shown that 2D:4D predicts speed on a range of attentional and visual discrimination tasks, such as targeting, vigilance, and camouflage breaking (31, 32). More generally, enhanced androgenic activity, either as a consequence of higher circulating hormone levels or greater receptor sensitivity (33), has been found to stabilize visual attention, reduce distraction by irrelevant stimuli (34), maintain search persistence (8), and increase visuomotor skills such as scanning and speed of reactions (9). Noise trading, unlike more analytic forms of trading, requires these physical skills because traders must scan the screens for extended periods of time and react quickly when an opportunity arises. The traits listed here may confer an advantage on traders pitted against a fast-moving market.
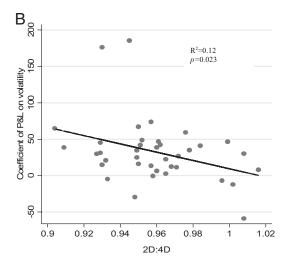
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Fig. 3. Circulating testosterone, volatility, and P&L. (*A*) The difference in each trader's P&L between days of high and low morning testosterone plotted against their 2D:4D. (*B*) Traders' 2D:4D plotted against the sensitivity of their P&L to changes in volatility. The plot was derived in 2 stages: First, each trader's P&L, recorded over a 20-month period, was regressed against the volatility of the Euribor futures contract over the same period. The slope of the resulting curve gave us a measure of the sensitivity of each trader's P&L to changes in volatility. Second, the slope of each trader's curve was plotted against his 2D:4D. The two outlier data points were handled by robust regression and did not distort the results.

In this second line of analysis, we used the volatility of Euribor (3-month European interbank rates) as a proxy for market volatility. Euribor is one of the core assets traded on this floor, and its variance displayed a high correlation with P&L over a 20-month period averaged from all traders ($R^2 = 0.735$, $P < 0.0005$, $n = 20$). We first estimated a regression coefficient for each trader, which displayed how his P&L responded when Euribor volatility increased or decreased. We next regressed these coefficients against each trader's 2D:4D and found that the regression was significant ($R^2 = 0.12$, $F_{1,36} = 5.61$, $P = 0.023$; Fig. 3*B*). Regressing these coefficients against experience, on the other hand, did not give a significant result ($b = 12.9$, $P = 0.301$). Put simply, these results show that the lower a trader's 2D:4D, the more money he makes as volatility increases.

Discussion

We have found that digit ratios together with years of training predict a high-frequency trader's long-term P&L. Our model suggests a roughly even split between the contributions of biology and experience; biology in this case being the organizing effects of prenatal androgens on an individual's body, brain, and behavior. As digit ratios are set early in life, there can be no feedback mechanism of the sort one might find between P&L and circulating testosterone (30); digit ratios predict profitability, not vice versa. Moreover, the correlations we have observed in this cohort between digit ratios and profits hold true over a 20-month period; and the correlations between digit ratios and years of experience hold over many years, in both bull and bear markets, so the survival of low-2D:4D traders does not appear to depend on particular market conditions.

The finding that a marker of prenatal testosterone levels predicts a trader's long-term profitability dovetails with an earlier study, which found that levels of circulating testosterone predict short-term profitability (30). Indeed, 2D:4D gauges the sensitivity of P&L to changes in circulating testosterone. Taken together, these two studies lend support to the organizational/activational hypothesis of steroid action.

Finally, the results of the current study suggest that the traits signaled by 2D:4D are likely to confer the greatest advantage in noise or high-frequency trading, an occupation that requires, in addition to the ability to take risks, heightened vigilance and quick reactions. Our findings may therefore be replicated among amateur day traders, high-frequency traders at other banks, and local traders on the floors of stock and futures exchanges. But the correlation may weaken among traders who require additional skills. Flow traders at the investment banks, for example, engage in high-frequency trading, but they also require an ability to deal with clients and a sales force, and these traders often make the bulk of their P&L from client business rather than pure risk-taking. The correlation could even reverse sign among traders who adopt a more analytical and long-term approach to the markets. For example, arbitrage traders at the investment banks and hedge funds are increasingly hired from the math and science departments of universities, and one study, which looked at average digit ratios in university departments found that faculty from math, science, and engineering exhibited higher, more feminine digit ratios (35). A similar result may well be found among traders with a long-term holding period.

The financial markets are made up of many sectors and types of trading, and each of these may select for different biological traits. But if markets select traders on the basis of their profitability and their occupational preferences (36), then low-2D:4D traders will continue to influence asset prices and equilibria in some of these sectors. Contrary to the assumptions of the rational expectations hypothesis, financial market equilibria may be influenced as much by traders' biological traits as by the truth of their beliefs.

Materials and Methods

Subjects. During recruitment we approached potential subjects on the trading floor and invited them to participate in the study. They were given an introductory note that explained briefly that we were looking at the effects of prenatal testosterone on the shape of their right hand. No information was given about our hypothesis. Interested traders were informed that they would receive a summary of our findings; they were not offered payment. Of the traders asked to participate, all but 3 agreed. Before giving a handprint, all subjects completed a short questionnaire asking their age, years of trading, P&L history, number of older brothers, and whether they had broken the index or ring finger of their right hand. They also signed an informed consent form. All handprints, questionnaire data, and P&L from the bank were coded by an independent laboratory technician in Cambridge, so our analyses were conducted blindly with respect to the identity of the traders. The study was approved by the Ethics Committee of the School of Biological Sciences at the University of Cambridge.

Five of the traders volunteering for the study could not be included because they had broken either the index or ring finger of their right hands. From the remaining 49 subjects, 2 were subsequently excluded because their handprints

were of insufficient quality to be assessed, and 3 were excluded because they received a different compensation package from the other traders, making it difficult to compare their P&Ls (although retaining them in the study left all results significant).

P&L Sampling. During the study some traders left the firm while others joined, so for some traders we had less than 20 months of P&L data, and the dates of their samples varied. Traders' P&Ls are often correlated as they collectively go through good and bad times, so gauging one trader's performance relative to another may be misleading if we compare their P&Ls at different times. However, as reported above, we controlled for the possibility of a missing time variable affecting P&L.

2D:4D Measurement. 2D:4D was determined from right-hand measurements only, because right-hand digit ratios have been shown previously to display more robust sex differences and are thus thought to be more sensitive to prenatal androgens (37, 38).

When measuring 2D:4D from soft tissue, care must be taken to distinguish regular from irregular or secondary creases. Irregular creases form later than regular creases, after the 11th week of gestation when the fingers start to bend, disrupting the dermal surface (25, 39). For example, fingers often develop an extra crease that is parallel, but distal, to the metacarpophalangeal crease. When this pattern is found, digit measures are taken from the proximal crease. Also common is an oblique crease angled off from the proximal crease, giving the appearance of a horizontal Y, or several oblique creases feathering the major crease (25). In these cases, measurement is taken from the middle of the Y pattern. On rare occasions, the proximal regular crease may be broken or unconnected, indicating a gap in the digital pads during development, and the broken crease may overlap in the middle of the finger. In the one case in our study where this pattern occurred, we averaged measures from the 2 halves of the broken crease. Last, it is possible, but again rare, to encounter a major crease that is indiscernible among a pattern as complicated and unique as a fingerprint (39). The only print in our study to display this pattern had already been excluded because of a broken finger. Traders' handprints were measured for 2D:4D by one of the authors (J.M.C.) and by an independent observer using callipers accurate to 0.2 mm, and these measures displayed a high repeatability (intraclass correlation = 0.974).

2D:4D research has often encountered difficulties with behavioral variables, difficulties that have led to inconsistencies between published results.

It should be noted that these inconsistencies exist largely between studies measuring psychological variables, such as aggression, status seeking, and perceived social dominance (40). Variables such as these are notoriously difficult to define and measure with any degree of repeatability. However, complications are not so common in 2D:4D research looking at performance variables that can be measured with less ambiguity. For example, achievements in sports such as soccer (12) and skiing (14), and performance in running and athletics (41) are more easily measured, and thus they display more consistent relationships with 2D:4D. The financial markets offer particularly promising variables in this respect. Financial variables, such as P&L, volatility, and years of experience, are objective and readily measured. The objective nature of our dependent variables goes some way toward accounting for the high statistical significance of the relationships we observed.

Market Volatility. To measure asset price volatility, we used the annualized standard deviation of the price changes of the Euribor futures contract. A total of 77% of the traders traded a European interest rate future, and the other traders, whose main trading security was a stock index, also traded interest rate futures as a secondary trading instrument. The estimation of a coefficient relating variance of Euribor to P&L converged for 38 of the 44 traders.

Statistics. The right-skew in the P&L data was corrected by a Box-Cox transformation. All results remained significant or displayed greater significance and effect size if we used the alternative of a cube root or rank-order transformation. 2D:4D data approximated a normal distribution (SI). When reporting correlations with a single independent variable, we used Pearson correlation coefficient; where R^2 is reported instead, we were using a robust regression to dampen the effects of outlying data. Statistical analyses were performed with Stata, release 10/SE (Stata).

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