Revisiting the effect of red on competition in humans

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Bright red coloration is a signal of male competitive ability in animal species across a range of taxa, including non-human primates. Does the effect of red on competition extend to humans? A landmark study in evolutionary psychology established such an effect through analysis of data for four combat sports at the 2004 Athens Olympics [1]. Here we show that the observed pattern reflects instead a structural bias towards wins by red in the outcomes of the competition. Consistently, we find no effect of red in equivalent data for the 2008 Beijing Olympics, which present a structural bias towards wins by blue. These results refute past claims of an effect of red on human competition based on analysis of this system. In turn, this undermines the notion that any effect of red on human behavior is an evolved response shaped by sexual selection.

In animal species across a range of taxa, bright coloration is a secondary sexual character acting as a signal of male competitive ability [2]. In mandrills, for example, male rank is determined through contest competition, with marked reproductive skew in favor of top-ranking individuals. High rank is associated with better reproductive outcomes also in females, but here rank is inherited from the mother instead. As expected within the framework of Darwinian sexual selection [3, 4], the extent and intensity of red skin on the face of adult individuals vary with rank in males, but not in females [2, 5].

The relationship between red coloration and competition in non-human primates and other taxa raises an intriguing question [1]: does red have an effect on the outcome of human competitive interactions, shaped by similar evolutionary processes? Of course, humans do not present natural displays of conspicuous secondary sexual coloration. However, increased or decreased blood flow to the skin are linked to a range of emotional states, including anger and fear. This response may serve as a subtle cue of relative dominance during aggressive encounters, echoing the sexually selected response to red in other species.

Hill & Barton [1] reasoned that the effect may extend to artificial stimuli, for example wearing red during a physical contest. In an ingenious first test of this hypothesis, they exploited a structural feature of tournaments in four Olympic combat sports: boxing, taekwondo, Greco-Roman wrestling, and free-style wrestling. In these sports, contestants compete in pairs as red vs. blue, with distinctively colored clothing and/or equipment. In the 2004 Olympics, colors were assigned to contestants independent of ability. If red does confer a competitive advantage, as predicted, then contestants wearing red would be more likely to defeat their opponents, and more than half the contests would end in a win by red.

Data on outcomes in the men's divisions for the four sports at the 2004 Athens Olympics upheld this prediction [1] (Fig. 1**a**), and no effect was found in the two sports with women's divisions (taekwondo and free-style wrestling) [6]. These patterns were taken to support the hypothesis of a red advantage in human competitive interactions: red enhances performance, possibly acting as a cue of relative dominance when factors such as skill or strength are equally matched. At the proximate level, the effect was posited to operate through psychological or physiological (e.g., hormonal) influences on the red-wearing competitor, on his opponent, or both [6].

We present an alternative explanation, which fully accounts for the observed pattern without recourse to an effect of red on competitive outcomes. In the four sports analysed, the competition for a given weight class is arranged as a single-elimination tournament (Fig. 1**b**). While details vary across sports (Supplementary Information), generally the winner of a contest, or bout, proceeds to the next round in the competition "tree". In boxing and wrestling, the contestant placed at the top of the bout wears red, the one placed at the bottom wears blue; the pattern is reversed in taekwondo. A contestant's relative position, and thus the color he wears, may change between bouts, as he progresses through rounds in the tournament (Fig. 1**b**).

When the tournament structure is incomplete and contestants vary in skill level, the null distribution for the fraction of red wins can depart from 0.5, due to a bias towards wins by one color in the outcomes of the competition (Supplementary Information). Two sources of incompleteness are byes and walkovers, both of which result in "missing" bouts (Fig. 1**b**; Supplementary Information). Using a Monte Carlo simulation of competition [7] on the actual 2004 tournament structures, we numerically calculated the distribution of red wins under the null hypothesis (no effect of red), for different degrees of variance in competitor skill (Methods). Compared to

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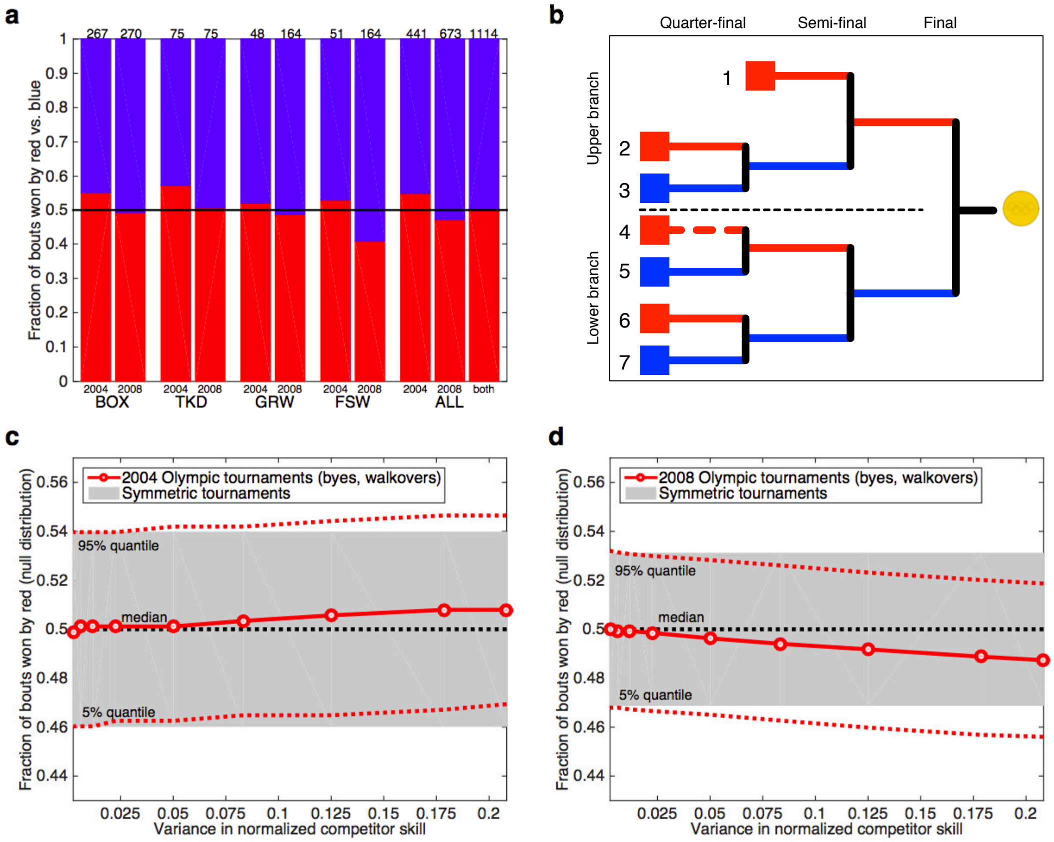

FIG. 1. **Testing the effect of red in Olympic contests.** **a**, Fractions of bouts won by contestants wearing red vs. blue in the male divisions of boxing (BOX), taekwondo (TKD), Greco-Roman wrestling (GRW), and free-style wrestling (FSW) at the 2004 Athens and 2008 Beijing Olympics, along with fractions when outcomes are aggregated over the four sports (ALL) by year (2004, 2008) or over the two years (both). The number of bouts in each group is reported above the corresponding bar. The horizontal line shows $f_{\mathrm{red}} = 0.5$. See Table I for details. **b**, Schematic representation of the structure of a single-elimination tournament for $n = 7$ contestants. Because n is not a power of 2, the outermost round is incomplete. In this case, contestant 1 does not compete in the quarter-final round, i.e., he is byed to the semi-final round. In each contest, or bout, the contestant at the top wears red, the one at the bottom wears blue. For example, contestants 2 and 3 wear red and blue, respectively, in the quarter-final round. The winner of this bout proceeds to the semi-final round (in blue), where he faces contestant 1 (in red). The bout between contestants 4 and 5 is won by walkover (dotted red line, indicating that contestant 4 withdrew or failed to show up). Contestant 5 proceeds to the semi-final round (in red), where he faces the winner of the 6–7 bout (in blue). **c,d**, Quantiles for the distribution of the fraction of red wins f_{red} under the null hypothesis on the actual asymmetric tournament structures in the 2004 Athens and the 2008 Beijing Olympics (red line) and an equivalently sized symmetric tournament (grey fill). In both cases, the distributions were evaluated by Monte Carlo at the locations of the red dots. Asymmetries in the tournament structures shift the null distribution away from a mean of $f_{\mathrm{red}} = 0.5$ as skill variance increases. These asymmetries induced a bias towards red in 2004 and towards blue in 2008. See text for details.

equivalent tournaments with no missing bouts, the null distribution for the incomplete tournaments shifts in favor of red wins as skill variance increases (Fig. 1**c**). This implies that a standard hypothesis test will overstate the statistical significance of any observed pattern favoring red (Supplementary Information), and a correctly parameterized test of the red hypothesis cannot be constructed without knowing the true variance in skill. A conservative interpretation, however, is that the pattern reported by Hill & Barton [1] reflects this underlying bias in the null distribution (Table I; Supplementary Information).

This interpretation is further supported by equivalent data for the 2008 Olympics (Supplementary Information). We find no evidence of a red effect (Fig. 1**a** and Table I), and Monte Carlo simulations show that in this case the pattern of incompleteness induces a bias towards wins by blue in the outcomes of the competition (Fig. 1**d**). Furthermore, data pooled over both years show no evidence of a red effect (Fig. 1**a** and Table I). Finally, an estimate of the statistical power indicates that if an effect does indeed exist in these data, it must be small, altering the outcome in no more than 1.3% of bouts relative to

Year	Test	Sport(s)	n_{red}	n	f_{red}	p-value
2004	Bouts	BOX	147	267	0.551	0.056
	Bouts	TKD	43	75	0.573	0.124
	Bouts	GRW	25	48	0.521	0.443
	Bouts	FSW	27	51	0.529	0.390
	Bouts	ALL	242	441	0.549	0.023
	Rounds	ALL	16	21	0.762	0.013
	Weight classes	ALL	19	29	0.655	0.068
2008	Bouts	BOX	133	270	0.493	0.620
	Bouts	TKD	38	75	0.507	0.500
	Bouts	GRW	80	164	0.488	0.652
	Bouts	FSW	67	164	0.409	0.992
	Bouts	ALL	318	673	0.473	0.929
	Rounds	ALL	8	25	0.320	0.978
	Weight classes	ALL	11	29	0.379	0.932
Both	Bouts	ALL	560	1114	0.503	0.440

TABLE I. **Tests of a red effect in Olympic contests.** Results for tests of a red effect in the male divisions of boxing (BOX), taekwondo (TKD), Greco-Roman wrestling (GRW), free-style wrestling (FSW), and aggregated over the four sports (ALL), at the 2004 Athens and 2008 Beijing Olympics. Tests denoted "bouts" compare the number of bouts won by red, n_{red}, to the n total wins. Tests denoted "rounds" compare the number of rounds with a majority of red wins, n_{red}, to the n total rounds. Tests denoted "weight classes" compare the number of weight classes with a majority of red wins, n_{red}, to the n total weight classes. In all cases, $f_{\text{red}} = n_{\text{red}}/n$. Reported are the results of one-sided binomial tests ($H_0 : f_{\text{red}} \leq 0.5; H_{\text{A}} : f_{\text{red}} > 0.5$), with $\alpha = 0.05$. None of the results are significant under a Bonferroni-adjusted threshold $\alpha_{\text{c}} = 0.003$ (Supplementary Information).

natural variation. In fact, this value likely overestimates the true impact, as it is calculated without accounting for the structural biases described above (Supplementary Information).

These findings suggest that red does not affect the outcomes of Olympic contests, challenging past claims about the role of color in human competitive interactions based on analysis of this system [1, 6]. Moreover, our analysis illustrates that confounding effects arising from non-independence and biases in the data-generating process, multiple hypothesis testing, and low statistical power can be subtle (Supplementary Information). Extreme caution is thus required in interpreting related results derived from other systems [reviewed in 8, 9].

A large body of work has developed over the past decade, building on the hypothesis of a sexually selected response to red in humans [reviewed in 8, 9] — indeed, the effect of red on human behavior has come to be regarded as one of the best established, and most salient, in the field of color psychology, with important practical applications [10]. Our results refute the foundational finding to this body of work [1], casting doubt on claims that any effect of red on human competition has an evolutionary basis. In what way evolution has shaped the human response to color, and how this is reflected in present-day human behavior, remain open questions.

Methods

Details of the data collection and analysis are in the Supplementary Information. Null distributions for f_{red} were obtained by Monte Carlo simulation of single-elimination tournaments, by weight class, sport, and year. Results were then aggregated for analysis. Each simulated weight class used its observed tournament structure, including asymmetries (byes, walkovers). Competitors were assigned randomly to initial tournament positions, with skill levels drawn i.i.d. from a symmetric Beta distribution: $x \sim \text{Beta}(\beta, \beta)$. Bout outcomes were evaluated progressively over rounds. When a pair of competitors r and b faced off, r advanced to the next round with probability $x_r/(x_r + x_b)$ [7] (Supplementary Information).

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