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On Being Unpredictable and Winning

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In theory, it can be strategically advantageous for competitors to make themselves unpredictable to their opponents, for example, by variably mixing hostility and friendliness. Empirically, it remains open whether and how competitors make themselves unpredictable, why they do so, and how this conditions conflict dynamics and outcomes. We examine these questions in interactive attacker–defender contests, in which attackers invest to capture resources held and defended by their opponent. Study 1, a reanalysis of nine (un)published experiments (total $N = 650$), reveals significant cross-trial variability especially in proactive attacks and less in reactive defense. Study 2 ($N = 200$) shows that greater variability makes both attacker's and defender's next move more difficult to predict, especially when variability is due to occasional rather than (in)frequent extreme investments in conflict. Studies 3 ($N = 27$) and 4 ($N = 106$) show that precontest testosterone, a hormone associated with risk-taking and status competition, drives variability during attack which, in turn, increases sympathetic arousal in defenders and defender variability (Study 4). Rather than being motivated by wealth maximization, being unpredictable in conflict and competition emerges in function of the attacker's desire to win "no matter what" and comes with significant welfare cost to both victor and victim.

Keywords: behavioral game theory, predator–prey dynamics, testosterone, sympathetic arousal

In the aftermath of a civil war marked by ethnic cleansing and genocide, former diplomat Richard Holbrooke mediated a peace settlement between the leaders of Serbia and Bosnia-Herzegovina. His memoires recount that, at some point, the Serbian army general Ratko Mladic "suddenly … erupted [into] a long, emotional diatribe. … I did not know if his rage was real or feigned, but this was the genuine Mladic, the one who could unleash a murderous rampage" (Holbrooke, 1999; p. 150). Mladic's unexpected eruption reminds of former U.S. president Nixon who, at the height of the Vietnam War, pondered:

> I want the North Vietnamese to believe I've reached the point where I might do anything to stop the war. We'll just slip the word to them that … he has his hand on the nuclear button and Ho Chi Minh himself will be … begging for peace. (Haldeman, 1978, p. 83)

And it reminds of Donald Trump's first foreign policy speech:

> I have a simple message for [ISIS]. Their days are numbered. I won't tell them where and I won't tell them how. We must, we must as a nation be more unpredictable. We are totally predictable. We tell everything. We're sending troops … have a news conference. We have to … be unpredictable starting now. (New York Times, 2016)

In both international conflict and interpersonal competition, individuals sometimes erratically switch between hostile and friendly behavior, or between moving against and moving away (Hilty & Carnevale, 1993; Sinaceur et al., 2013). Such variability in conflict behavior may render one unpredictable to outsiders and some have suggested that it can be functional: "Sometimes [it] can be wise to simulate madness" (Machiavelli, 1531/2013, p. 68) and

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The authors report how the authors determined the authors' sample size, all data exclusions, all manipulations, and all measures in the study. All data, analysis code, and background materials are available at https://doi.org/10.34894/WUTY3N. Study design and analyses were not preregistered.

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strategically advantageous to be unpredictable (Schelling, 1960). Yet four issues remain open that we aim to address. First, there is limited evidence that competitors are variable in their conflict behavior. Second, work in cognitive science calls into doubt whether variable mixing of actions during conflict makes competitors irreducible unpredictable to their opponents (Burns & Vollmeyer, 1998; Cooper, 2016; Sanderson, 2018; Wagenaar, 1972; Warren et al., 2018; Wong et al., 2021). Third, the biological and psychological mechanisms producing unpredictability remain poorly understood. Finally, we do not know how being (unpredictably) variable in one's behavior conditions conflict dynamics, individual payoffs, and the likelihood of winning.

Unpredictability in Conflict and Competition

The idea that being unpredictable can be strategically advantageous is at the heart of the conceptualization of conflict as a game of strategy (Camerer, 2003; Kimbrough et al., 2020; Schelling, 1960). In its simplest form, a game of strategy involves two agents each with two actions to choose from. Agents are assumed to be rational and risk neutral and expected payoff maximizing (viz., homo economicus), and conflict emerges when the outcome that one agent prefers is at odds with the outcome preferred by the other agent (De Dreu, 2010; Pruitt, 1998; Pruitt & Kimmel, 1977; Rusbult & Van Lange, 2003; Schelling, 1960). A prime example is the prisoner's dilemma game in which agents can choose between "cooperate" and "defect." All else equal, to maximize personal payoffs, agents in the prisoner's dilemma game should defect regardless of whether they expect the other to cooperate, or to defect as well (Camerer, 2003; Halevy & Chou, 2014; McClintock & Liebrand, 1988; van Dijk & De Dreu, 2021).

In games of strategy like the prisoner's dilemma, randomly switching between actions has no clear advantages, and agents do not need to care about their counterpart being able to predict their next move (Axelrod & Hamilton, 1981; Camerer, 2003; Sheldon, 1999). This is different in games of strategy with its equilibrium in mixed strategies, such as hide-and-seek games (Bar-Hillel, 2015; Lahat-Rania & Kareev, 2023), best-shot-weakest link games (Clark & Konrad, 2007), inspection games (Nosenzo et al., 2016), and colonel-blotto and attacker–defender contest games (Chowdhury et al., 2021; Chowdhury & Topolyan, 2016; De Dreu & Gross, 2019b; Hunt & Zhuang, 2023; Roberson, 2006). In hide-and-seek games, for example, hiders want to be where seekers are not looking, yet seekers want to look where hiders are hidden. Accordingly, when hiders expect that seekers search location x, they want to hide in location y, but seekers realizing this may search location y and this makes hiding in location x most attractive. In inspection games, likewise, managers want to not inspect workers who comply, because inspection is costly. But workers will not comply when not inspected, because compliance is costly. Accordingly, what is in the worker's best interest (e.g., comply or shirk) fully depends on what the manager decides (e.g., inspect or not inspect), and vice versa.

As these examples show, agents personally benefit from mismatching their opponent's action in conflict games that have their equilibrium in mixed strategies. In attacker–defender contests, for example, attackers benefit from investing in conflict when their defenders do not, akin to nonhuman predators wanting to attack when their prey is expecting it the least (Dugatkin & Godin, 1992), revisionist states wanting to invade when their neighbors are poorly defended (Jordana et al., 2009), and terrorists wanting to avoid areas where security forces are expecting them (Arce et al., 2011; also see Bar-Hillel, 2015). And precisely for these reasons, it is each agent's best interest to vary their conflict behavior nonsystematically so that opponents cannot predict one's next move—switching where to hide and seek, inspecting targets at random points in time, and erratically alternating between laying low and lashing out when attacking opponents (e.g., De Dreu & Gross, 2019b; Emara et al., 2017; Erev & Roth, 1998; Schelling, 1960).

Whereas conflict with its equilibrium in mixed strategies motivates to be unpredictable, and individuals can be expected to nonsystematically vary whether and how much they invest in conflict, earlier work returned mixed evidence, with some showing that participants mix strategies quite well and others rejecting such claims (for reviews and discussions, see e.g., Chiappori et al., 2002; Erev & Roth, 1998; Misirlisoy & Haggard, 2014). In contrast to stylized agents assumed to be motivated and capable to rationally maximize expected payoffs, people may be limited in the degree to which they vary actions both with the same or with different opponents. For example, people may want to avoid the risk of losing and therefore, compared to "homo economicus" agents, reduce the amount they invest in attack and increase the amount they invest in defense (Chowdhury et al., 2018; Meder et al., 2023; Sheremeta, 2013; Yang et al., 2020). In both cases, the range of possible actions is reduced, and with that variability in conflict behavior may be reduced as well. Relatedly, survival threat can make people rigid in their thinking (Porcelli & Delgado, 2017; Pratto & John, 1991; Staw & Ross, 1989) and lead them to rely on a "better-safe-than-sorry" heuristic by excluding the option to not defend at all (Halevy, 2017; Jervis, 1978; Simunovic et al., 2013; Walker et al., 2018; Zou et al., 2020). Acting on a "better-safe-than-sorry" heuristic (viz., "minimax" strategy; Erev & Roth, 1998; Von Neumann & Morgenstern, 1944) would, for example, increase overall expenditure on defense and make defenders less variable in their actions. The other way around, attackers may be motivated not only to maximize earnings but also, or exclusively so, to win the conflict (Cason et al., 2020; Thaler, 1988; van den Bos et al., 2008). This could increase both the number and intensity of attacks beyond strict randomization.

Apart from current evidence being limited, it is presently unknown whether and how mixing actions across trials and opponents makes competitors unpredictable to the degree that opponents have difficulty anticipating their next move. In general, being variable not necessarily means that one is irreducibly unpredictable. For example, an aggressor who systematically alternates between minimum and maximum investment in attack would be highly variable yet also is, at least after some time, quite predictable—the same level of variability can be achieved by varying conflict expenditures more or less systematically, and any systematicity can make one behaviorally variable but predictable at the same time. Because people have difficulty generating randomness (Baddeley et al., 1998; Lahat-Rania & Kareev, 2023; Sanderson, 2018; Wagenaar, 1972), it may well be that people mix conflict actions in such a nonrandom, systematic way that they are variable but also predictable.

Given that we presently have limited insight into whether and how (unpredictably) variable people are in conflicts with its equilibrium in mixed strategies, we also poorly understand whether and how being (unpredictably) variable in one's conflict investments shapes interaction dynamics and conflict outcomes. We lack insight in whether and how individuals across repeated interactions respond, in thinking and doing, to their opponent's (unpredictably) variable behavior. And to the best of our knowledge, there is no empirical evidence to support the theoretical proposition that being unpredictable can be strategically advantageous (Machiavelli, 1531/2013; Schelling, 1960) either when contestants interact once or repeatedly across a series of contest trials.

Overview of the Present Research

The present research addressed the three open issues identified above: (a) Do people in conflict (with a unique mixed-strategy equilibrium) variably mix whether and how much they invest in conflict; (b) does such variable mixing render competitors unpredictable to their counterpart; and (c) how does being (unpredictably) variable influence conflict dynamics and outcomes? We examined these issues in the realm of the attacker–defender contest, a conflict game with a discrete rather than binary action space—parties could invest nothing, something, or a lot in conflict either to win and exploit the counterpart (viz., "greed" or appetitive competition in attackers) or to minimize loss and protect against exploitation (viz., "fear" or aversive competition in defenders; Coombs, 1973; De Dreu & Gross, 2019b; Messick & McClintock, 1968; Ten Velden et al., 2009). Thus, in addition to the three open issues that motivated the present study, we explored (d) whether and how the psychological underpinnings of attack and defense shape variable mixing and unpredictability during conflict.

To answer our research questions, we proceeded in three steps. First, to detect (differences in) variable mixing during attack and defense, we combined and reanalyzed the data of seven published and two unpublished attacker–defender contest experiments (Study 1). To examine whether and how mixing actions rendered individuals unpredictable to their counterpart, we performed Study 2. To shed light on the neuropsychological underpinnings of variable mixing during attack and defense, we examined how variability in conflict behavior related to individual differences in basal testosterone and sympathetic arousal (Studies 3 and 4). All data and code can be found at De Dreu (2023).

Properties of Attacker–Defender Contests

In its most basic form, the attacker–defender contest involves an Attacker A and Defender D each with an endowment e from which they can invest x in the contest (with $0 \le x \le e$), simultaneously and without communication. Investments are nonrecoverable, akin to resources wasted on conflict. Yet when $x_A > x_D$, A(ttacker) wins the contest and earns the noninvested resources from D(efender) ($e_D - x_D$). These "spoils of war" are added to the attacker's noninvested resources, yielding an earning of $r_A = 2e - (x_A + x_D)$. In this scenario, the defender earns $r_D = 0$. When $x_A \le x_D$, both attacker and defender earn their noninvested resources ($e - x_A$, x_D). As such, the game is formally equivalent to a contest with as contest success function $f = x_A{}^m/(x_A{}^m + x_D{}^m)$, where f is the probability that the attacker wins, $m \to \infty$ for $x_A \ne x_D$ and $f = 0$ if $x_D = x_A$ (De Dreu et al., 2015; Meder et al., 2023).

For $e = 10$ per trial (as used in the experiments reported herein), and assuming that participants are risk neutral and invest to maximize personal earnings, the contest has a unique Nash equilibrium in mixed strategies. Specifically, the probability p of investing x in attack is $p(x = 1) = 2/45$, $p(x) = p(x - 1)[(12 - x)/(10 - x)]$ for $2 \le x \le 6$, and $p(x) = 0$ for $x \ge 7$. For defense, the probability p of investing y in defense is $p(y) = 1/(10 - y)$ for $0 \le y \le 5$, $p(y = 6) = 1 - [p(y = 0) + \ldots + p(y = 5)] = 0.15$, and $p(y) = 0$ for $y \ge 7$ (De Dreu et al., 2015, 2021; Meder et al., 2023). This implies that participants should invest, on average, $x_A = 2.62$ in attack and $x_D = 3.38$ in defense and that across trials, investments should vary with variance $v_A = 6.12$ for attack and $v_D = 3.68$ for defense. We note that such cross-round variability is assumed to be nonsystematic; yet, whether this indeed is the case for humans remains an empirical question.

In attacker–defender contests with $e = 10$, payoff-maximizing contestants should never invest more than six; investments $7 \le x \le 10$ are out-of-equilibrium and reminiscent of extreme actions like "brinkmanship" (Frank, 1988; Schelling, 1960) and "pondering the nuclear option" (viz., Mutual Assured Destruction; Jervis, 1978). For example, while an attacker may win the conflict by investing all their 10 endowment points, they can maximally earn 10 points back by doing so and only in the unlikely case that the defeated defender did not invest anything in defense. In this case, they could have guaranteed earnings of 10 by not investing anything into conflict in the first place. In game-theoretic terms, an investment of $x_A = 10$ is (weakly) dominated by $x_A = 0$. Because such extreme behaviors are considered irrational from a strict payoff-maximizing perspective, they should not be played according to game theory (De Dreu et al., 2021; Meder et al., 2023). At the same time, extreme risk aversion among defenders may lead them to invest out-of-equilibrium (e.g., "better to live poor than to die rich") and being motivated to "win-at-all-cost" may lead attackers to perform such extreme actions (Dechenaux et al., 2015; Loewenstein, 1996; Malhotra, 2010; Zou et al., 2014). Importantly, performing such extreme actions extends the space of viable actions, thereby allowing to increase the possible variability in behavior, making players comparatively more unpredictable to their opponents and helping defenders survive and attacker to win. If people are simply motivated to win whatever it takes, they may consider playing dominated, out-of-equilibrium actions.

Study 1

Method

Identifying Eligible Studies for Reanalysis

In a first step performed in January 2022, we combined and integrated nine experiments from our own research laboratory, including Study 4 here below, that (a) used the attacker–defender contest, (b) had at least five consecutive investments in attack and defense so that cross-round variability in investment could be assessed, and (c) provided in between trials full feedback on the trial outcomes so that participants could predict, in theory, their counterpart's next move. In June 2022 we searched Google Scholar and Web of Science for additional studies for possible inclusion in the reanalysis. Search terms included (variations on) "attack–defense," "attacker–defender," and "asymmetric contest." We also searched all citations to published work on attacker–defender contests. No additional experiments were found that could be included in the reanalysis. This is not surprising given our restrictive inclusion criteria and because the attacker–defender contest is a recent advance in the behavioral game literature (De Dreu & Gross, 2019b) with most work being theoretical rather than experimental (for a review, see

Hunt & Zhuang, 2023). In short, to our knowledge, all studies available for our research questions are included in the reanalyses (i.e., there is no file drawer).

Study Designs and Main Features

All experiments were performed in behavioral laboratories, were fully incentivized, void of deception, and with methods and procedures largely like those in Studies 3 and 4 reported below (for an example of instructions for a random-matching protocol experiment, see De Dreu et al., 2019). Five experiments used a random-partner matching protocol with attackers and defenders being randomly rematched on each new round of the contest (with either 30 or 60 rounds; total $N = 276$). The other four experiments used fixed-partner matching protocols with attackers and defenders nested in dyads for repeated interaction (with between 20 and 90 rounds in total; total $N = 374$; see Tables 1–2).

In theory, the experimental protocol should not matter for investment or variability. However, being unpredictable may be more important during repeated interactions as it prohibits being exploited by the other party. In addition, during repeated play, participants may adapt conflict investments to their competitor's previous investments, and this may escalate the conflict. For example, a defender paired to an attacker who occasionally invests out-of-equilibrium may be forced to invest out-of-equilibrium themselves as well. Conversely, defenders may occasionally initiate out-of-equilibrium investments to signal toughness and to discourage their attackers.

Measures

For each experiment, we extracted the per round conflict investment in attack or defense (range between 0 and 10) and computed (sample size weighted) average investment in attack and defense, the average earning for attacker (range between 0 and 19) and defender (range between 0 and 10), and the number of contest rounds where attackers (defenders) successfully defeated (defended against) the defender (attacker; Tables 1–2).

Our main variable of interest was cross-round variability in conflict investment. As noted above, the attacker–defender contest has its equilibrium in mixed strategies, and we have precise probability estimates for each investment level x ($0 \leq x \leq e$) (De Dreu et al., 2015, 2021; Meder et al., 2023). We operationalized cross-round variability in two complementary ways. First, we identified the relative frequency with which participants chose each possible investment level across rounds. This empirical distribution can be compared to the game-theoretic probability distribution that is expected under rational play (see Figure 1A and 1B). Second, we computed for each participant in each of the nine experiments the variability v as the deviation between investment x from the mean investment m across all rounds t: $v = \Sigma(x - m)/t$ (Figure 1C). Parameter v thus provides a point estimate that can be related to contest outcomes without having to control for for example, mean investments and without having to make assumptions about the (differences in probability distributions in) actual investments made during attack and defense. Parameter v serves to identify to what degree competitors can make themselves unpredictable to their opponents in further analyses (see Study 2 in particular).

Results

Analysis of average conflict expenditures confirmed that mean investment in attack is below to that in defense ($M_A = 4.404$ vs. $M_D = 5.236$; Cohen's $d \pm SE_g = 0.60 \pm 0.135$, 95% CI [0.332, 0.860], $z = 4.425$, $p < .001$; based on $N = 382$). Furthermore, and in line with game theory and the mixed-strategy equilibrium properties of the attacker–defender contest, investments in attack and defense are variable across trials (Figure 1A and 1B). Cross-trial variability v in investment for both attack and defense closely match game-theoretic equilibrium predictions ($v_A = 6.12$ for attack and $v_D = 3.68$ for defense) for one-shot conflict interactions, and there is greater variability in attack than in defense (Cohen's $d = 0.438$, 95% CI [0.29, 0.58], $z = 5.948$, $p < .001$; Table 3). In repeated interactions, variability exceeds equilibrium predictions for both attack and defense (Figure 1C).

Table 1

Study Characteristics of the Experiments Included in the Meta-Analysis and Their Descriptive Statistics for Cross-Round Variability (VAR) and Proportion of Out-of-Equilibrium (O-E) Investments for Attack and Defense

Study[a]	*N* (no. trials)	VAR attack; defense (*SD*)	*t* test[b]	O-E attack; defense (*SD*)	*t* test[b]
One-shot					
De Dreu et al. (2019; Exp. 1a)	27[a] (60)	4.885 (3.149); 2.998 (2.677)	2.32**	0.217 (0.227); 0.089 (0.901)	3.03**
De Dreu et al. (2019; Exp. 1b)	58[a] (30)	6.897 (5.377); 4.741 (3.888)	3.10**	0.376 (0.289); 0.493 (0.264)	−2.95**
De Dreu et al. (2019; Exp. 2a)	80[c] (30)	5.535 (4.770); 3.605 (2.432)	2.29*	0.499 (0.217); 0.300 (0.267)	3.66**
De Dreu et al. (2019; Exp. 2b)	84[c] (60)	5.594 (4.139); 3.780 (1.977)	2.52*	0.275 (0.277); 0.184 (0.119)	1.93^
Rojek-Giffin et al. (2020)	27[a] (60)	3.639 (2.951); 2.467 (2.335)	2.69**	0.171 (0.253); 0.553 (0.242)	−6.38**
Repeated					
De Dreu et al. (2016)	40[d] (20)	7.224 (5.631); 4.068 (2.977)	2.91**	0.238 (0.250); 0.392 (0.308)	−2.95**
De Dreu (2019)	116[d] (30)	5.689 (4.196); 4.146 (2.628)	2.77**	0.347 (0.295); 0.364 (0.295)	−1.01
Reddmann et al. (2021)	112[d] (60)	8.073 (4.678); 5.270 (2.938)	1.56	0.309 (0.313); 0.330 (0.299)	−1.09
Present Study 4	106[d] (90)	6.806 (2.355); 6.170 (2.303)	5.74**	0.297 (0.228); 0.377 (0.294)	−3.60**

Note. Exp. = experiment.
[a] Within-subjects design with participants investing in one block of trials as attacker and in another block of trials as defender, each trial with a new opponent. [b] Test statistics are based on paired-sample t tests for within-subjects and dyadic designs and independent sample t tests for between-subjects designs. [c] Between-subjects design with participants investing as attacker or as defender, on each trial with a new opponent. [d] Repeated-interaction design in which participants are paired in dyads and one invests as attacker the other as defender.
^ $p \leq .10$. * $p \leq .05$. ** $p \leq .01$.

Table 2
Study Characteristics of the Experiments Included in the Meta-Analysis, and the Associations Between Variability (VAR) and Out-of-Equilibrium (O-E) Investments in Attack and Defense and Conflict Success (Victory/Survival) and Wealth (Earnings)

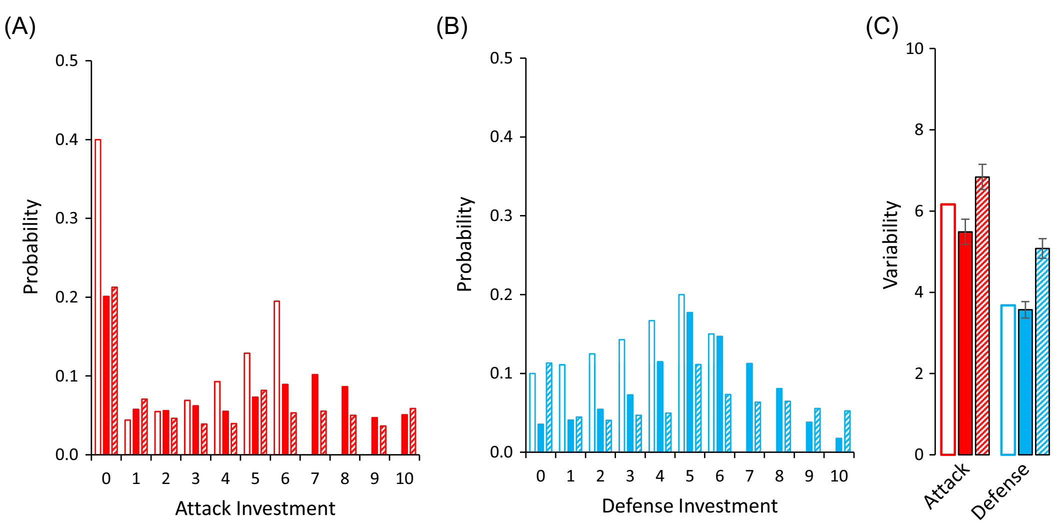
Study	$r_{\text{VAR, success}}$ Attack (defense)	$r_{\text{VAR, wealth}}$ Attack (defense)	$r_{\text{O-E, VAR}}$ Attack (defense)	$r_{\text{O-E, success}}$ Attack (defense)
One-shot				
De Dreu et al. (2019; Exp. 1a)	0.15 (−0.593**)	−0.084 (−0.756**)	0.119 (0.445**)	0.885*** (0.147)
De Dreu et al. (2019; Exp. 1b)	0.239^ (−0.437**)	0.026 (0.213)	0.048 (−0.405**)	0.878*** (0.457**)
De Dreu et al. (2019; Exp. 2a)	0.463** (−0.505**)	−0.272^ (−0.094)	−0.311* (−0.048)	0.919*** (0.708**)
De Dreu et al. (2019; Exp. 2b)	0.314* (−0.041)	−0.318* (−0.180)	0.099 (0.479**)	0.865*** (0.425**)
Rojek-Giffin et al. (2020)	0.299 (−0.660***)	−0.089 (−0.070)	0.120 (−0.028)	0.828*** (0.366*)
Repeated				
De Dreu et al. (2016)	0.126 (−0.113)	−0.232 (−0.041)	0.314* (−0.126)	0.062 (−0.150)
De Dreu (2019)	0.310* (−0.006)	−0.105 (0.044)	0.273* (−0.002)	0.566** (0.450**)
Reddmann et al. (2021)	0.630** (−0.495**)	0.087 (−0.257*)	0.085 (−0.061)	0.516*** (0.311**)
Study 4	0.404** (−0.299*)	−0.011 (−0.063)	0.353** (0.121)	0.638** (0.240^)

Note. Cell entries are zero-order correlations between variables of interest. Exp. = experiment.
^ $p \leq .10$. * $p \leq .05$. ** $p \leq .01$. *** $p < .001$.

The variability v shown in Figure 1C not necessarily reflects that individuals mix conflict investment unpredictably (Figure 1A and 1B)—the same variability v can be achieved through different means and indeed, average investment in attack and in defense was (substantially) above the mean expected in equilibrium ($x_A = 2.62$ and $x_D = 3.38$). Human competitors waste 46.2% of their collective resources on conflict, 16% more than what is predicted under the assumptions of rational selfish play. This is because, as can be seen in Figure 1A and 1B, individuals frequently chose out-of-equilibrium investments in both attack and defense (i.e., $x > 6$), with the proportion for out-of-equilibrium defense expenditures exceeding that for attack in repeated but not one-shot conflict interactions (Figure 2A, and Table 3). The variability in attack and defense investment appears partially achieved by extreme conflict investments that are irrational from a strict pay off-maximizing perspective (further see Study 2 here below).

Fitting the observation that individuals occasionally invest out-of-equilibrium, variability in defense investments was negatively associated with postcontest wealth in both defenders and attackers (Figure 2B and Table 4). Increased variability was costly and wasteful. And whereas defense variability did not relate to defender survival, both out-of-equilibrium investments and

Figure 1
Variability in Investment in Attack and Defense



Note. (A) Occurrence of possible investment levels in attack as expected by rational choice actors (mixed-strategy equilibrium, open bars), in one-shot interactions (observed, solid bars; $N = 172$) and in repeated interactions (observed, dashed bars; $N = 192$). (B) Occurrence of possible investment levels in defense as expected by rational choice actors (mixed-strategy equilibrium, open bars), in one-shot interactions (observed, solid bars; $N = 168$) and in repeated interactions (observed, dashed bars; $N = 192$). (C) Observed variability in attack exceeds that in defense in one-shot interactions (solid bars) and, in repeated interaction, both attackers and defenders (dashed bars) exceed game-theoretic equilibrium predictions (open bars). See the online article for the color version of this figure.

Table 3
Effect Size Estimates (Cohen's d) and 95% Confidence Intervals for Investment Variability (VAR) and Out-of-Equilibrium Investments (O-E) in Attack Versus Defense

Effect size (attack vs. defense)	VAR	Proportion O-E
One-shot game		
Effect size [95% CI: *LL*, *UL*]	0.457 [0.255, 0.658]	0.007 [−0.198, 0.213]
$Q(w)$	0.287	48.036***
Repeated game		
Effect size [95% CI: *LL*, *UL*]	0.419 [0.212, 0.583]	−0.183 [−0.327, −0.039]
$Q(w)$	1.681	4.938
Overall		
Effect size [95% CI: *LL*, *UL*]	0.440 [0.29, 0.58]	−0.121 [−0.238, +0.003]
$Q(w)$	2.035	55.186***

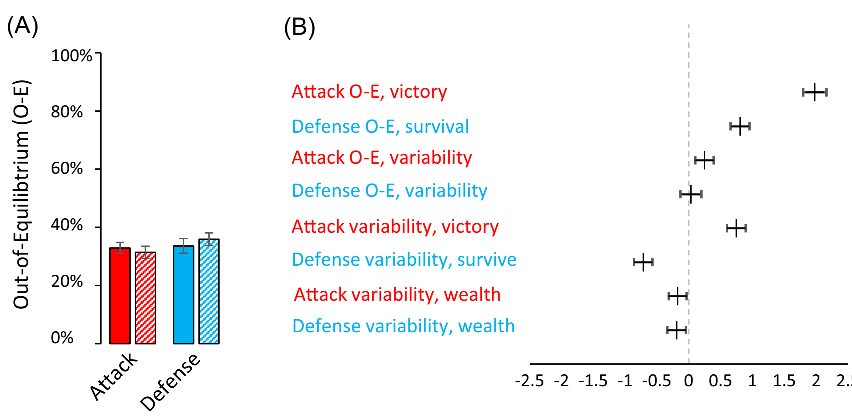
Note. Effect sizes (Cohen's *d*). 95% CI = 95% confidence intervals; *LL* = lower limit; *UL* = upper limit; $Q(w)$ = effect size heterogeneity across studies.
*** $p \leq .01$.

variability in attack increased the likelihood that attackers emerged victorious and defeated their defenders (Figure 2B). Variability in attack reduced wealth but increased the likelihood of winning the contest.

Study 2

The reanalysis of past experiments in Study 1 showed clear evidence that participants in attacker–defender contests are variable in their behavior across rounds, both with different opponents and when paired to the same opponent for multiple trials. What the reanalysis cannot show, however, is that such cross-round variability makes competitors unpredictable to their opponents. Therefore, we approached this question in two complementary ways. First, we examined whether participants in Study 1 made investments in identifiable ways. We collapsed data from each experiment and created unique blocks of five consecutive investments. Sequences of five trials were chosen for three reasons. First, there is some evidence that people can detect systematicity after ∼5 sequential actions and predict the next action above-chance level (Erev & Roth, 1998). Second, and relatedly, we have recently shown that people learn their opponent's acceptance levels in ultimatum bargaining games after approximately five interactions (Rojek-Giffin et al., 2023). Third, with discrete option space, five consecutive trials is the lowest number to identify deviations from four "systematic" strategies: stationary ($t_0 = t_1 = t_2 = \ldots = t_5$); ascending ($t_0 \leq t_1 \wedge t_0 < t_2 = \ldots \leq t_5 \wedge t_3 < t_5$); descending ($t_0 \geq t_1 \wedge t_0 > t_2 = \ldots \geq t_5 \wedge t_3 > t_5$); and alternating ($t_0 > t_1 \wedge t_1 < t_2 \wedge t_2 > t_3 \ldots$ or $t_0 < t_1 \wedge t_1 > t_2 \wedge t_2 < t_3 \ldots$). We coded each of the five-trial sequences in terms of these four strategies. Out of the 1,032 (1,008) attack (defense) sequences, only 29% (27%) fell into one of these four "systematic" sequences (Figure 3A). This suggests that in the experiments in Study 1, both attackers' and

Figure 2
Consequences of Variability in Attack and Defense



Note. (A) Sample-size weighted mean proportion ± *SE* of "out-of-equilibrium" (O-E) investment in attack and defense for one-shot (solid bars; $N = 194$) and repeated interactions (dashed bars; $N = 188$); (B) Sample-size weighted mean correlation between cross-round variability, out-of-equilibrium investment (O-E), and postconflict wealth and contest success for attack (red font) and defense (blue font; shown Cohen's *d* and 95% confidence intervals). Effect sizes with whiskers not including 0 (vertical dotted line) are statistically significant at $p < .05$ (based on $k = 9$ studies with $N = 650$). *SE* = standard error. See the online article for the color version of this figure.

Table 4

Effect Size Estimates (Cohen's d) and 95% Confidence Intervals for the Correlations Between Variability (VAR) and Out-of-Equilibrium (O-E) Investment and Success (Victory) and Wealth (Earnings) for Attack, Defense, and Their Difference

Effect size	$r_{\text{VAR, success}}$	$r_{\text{VAR, wealth}}$	$r_{\text{O-E, VAR}}$	$r_{\text{O-E, success}}$
One-shot game				
Attack [95% CI: *LL*, *UL*]	0.601 [0.397, 0.805]	−0.282 [−0.483, −0.081]	0.004 [−0.191, 0.209]	3.581 [3.258, 3.904]
Q(*w*)	3.867	7.820	10.348^	9.236
Defense [95% CI: *LL*, *UL*]	−0.927 [−1.14, −0.714]	−0.213 [−0.419, −0.008]	0.062 [−0.144, 0.268]	0.993 [0.779, 1.207]
Q(*w*)	24.621**	46.409**	52.437***	20.172**
Q(*b*)	103.176***	0.221	0.128	171.542***
Repeated game				
Attack [95% CI: *LL*, *UL*]	0.907 [0.691, 1.122]	−0.067 [−0.270, 0.136]	0.497 [0.291, 0.704]	1.216 [0.993, 1.439]
Q(*w*)	16.505*	3.717	4.815	15.937**
Defense [95% CI: *LL*, *UL*]	−0.513 [−0.721, −0.304]	−0.170 [−0.374, 0.033]	0.005 [−0.199, 0.208]	0.625 [0.416, 0.834]
Q(*w*)	17.444**	5.454	2.514	8.297^
Q(*b*)	86.176***	0.495	11.121***	14.354***
Overall				
Attack [95% CI: *LL*, *UL*]	0.746 [0.598, 0.894]	−0.176 [−0.312, −0.033]	0.246 [0.102, 0.389]	1.979 [1.796, 2.163]
Q(*w*)	24.455**	13.714	26.211*	164.735***
Defense [95% CI: *LL*, *UL*]	−0.715 [−0.86, −0.57]	−0.192 [−0.337, −0.047]	0.033 [−0.112, 0.177]	0.805 [0.655, 0.954]
Q(*w*)	49.492***	51.948***	55.101***	34.302**
Q(*b*)	185.929***	2.285	4.198*	94.647***

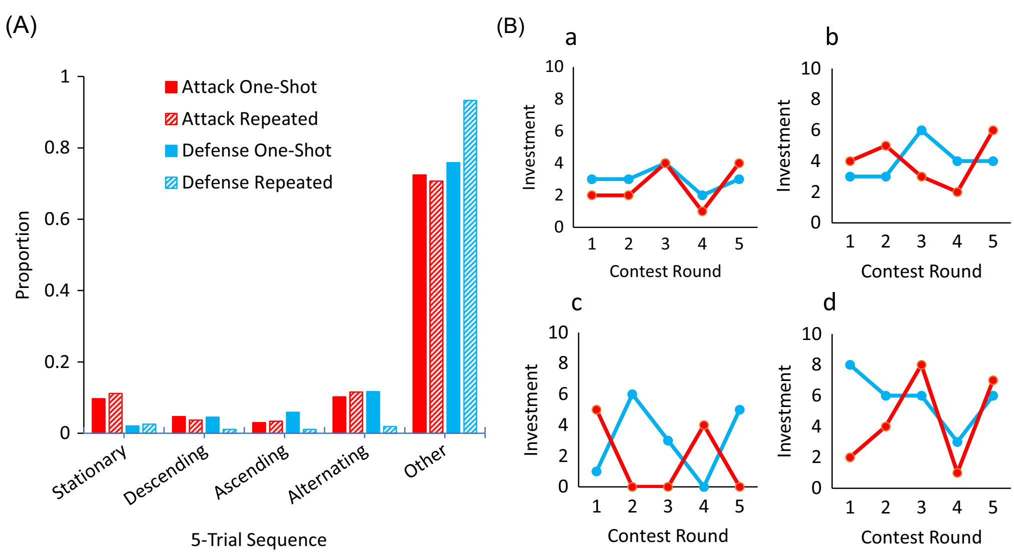
Note. Effect sizes (Cohen's *d*). 95% CI = 95% confidence intervals; *LL* = lower limit; *UL* = upper limit; *Q*(*w*) = effect size heterogeneity across studies; *Q*(*b*) = effect size heterogeneity across groups of studies (akin to a planned comparison).
^ $p \le .10$. * $p \le .05$. ** $p \le .01$. *** $p < .001$.

defenders' consecutive behavior could not be captured by simple sequences, like continuously increasing or decreasing investments or simply alternating between high and low investments, sequences that arguably are easy to predict.

That investments across trials vary in a seemingly nonsystematic manner not necessarily means that the individual's next investment is not thought through or conditional. For example, individuals may adapt their investment contingent on whether previous rounds were

Figure 3

Variability in Attack and Defense Investments Render the Individual Unpredictable



Note. (A) Proportion of attack and defense strategies that are simple and systematic (stationary, descending, ascending, or alternating) or more nonsystematic across five consecutive trials (one-shot interaction: solid bars; repeated interactions: dashed bars); based on the unique 1,008 five-trial sequences from the experiments incorporated in Study 1. (B) Examples of materials used in Study 2, where participants estimated what attacker (red player) and defender (blue player) would invest on Round 6. Panels vary from lower (a) to higher (d) variability in attack. Participants saw the 5-round sequence for the attacker and defender player and had to guess the 6th round investments for each player, respectively. See the online article for the color version of this figure.

won or lost (e.g., a win-stay/loose-shift strategy; Messick & Liebrand, 1995; Vlaev & Chater, 2006) or they may adapt their investment contingent on their opponent's previous move (viz., *k*-level reasoning; Rojek-Giffin et al., 2020). What matters more here, however, is whether and to which degree counterparts, with some knowledge about the history of play, can predict the individual's next move with above-chance accuracy. If the empirically observed cross-round variability in the studies included in the meta-analyses provides (more or less hidden) clues to what attackers and defenders do next, we should see above-chance prediction accuracy. If, however, cross-trial variability creates unpredictable competitors, we should see prediction accuracy to be low and at, or close to, chance level.

Method

Research Ethics and Sample Size

Study 2 was performed online through the Prolific platform with $N = 200$ (48% female, 1% not indicated; mean age 29.18 years). The study received ethics approval (Leiden Psychology Ethics Board 2021-11-12-Author-V1-3542). Participants provided written informed consent and were debriefed afterward. They received a participation fee of 3.15 Great British Pound and an additional 0–4 Great British Pound depending on their performance during the experiment. The experiment did not use deception.

Upon providing informed consent, participants read a brief description of the attacker–defender contest and were told that they would observe a series of investments of a red (attacker) and blue (defender) player. It was made clear that series shown were from individuals who had actually engaged in the contest and that action–reaction patterns were real. Participants answered three questions to probe their comprehension and when having answered all three correctly were shown five decision rounds between the red and the blue player in graphic form (see Figure 3B for examples). Their task was to predict what red and blue players invested on the 6th decision round. Participants were reminded that red and blue could both invest anywhere between 0 and 10, and that they could enter their prediction for the sixth decision round by entering a number between 0 and 10 for the red player and for the blue player. Correct estimates would earn the participant 1 Great British Pound.

In total, participants were shown 20 graphs of varying variability in attacker investments. The 20 graphs shown were drawn from 725 diagrams showing the five consecutive investments of an attacker and their defender in the 130 blocks from the repeated-interaction experiments included in the meta-analysis. To ensure that the full range of variability was presented to each participant, we first divided up the 725 diagrams into four quartiles of variability—wherein Quartile 1 contained all five-trial chunks whose variance was between the 0th and 25th percentile of attacker variance (Figure 3B, Panel a), Quartile 2 contained all five-trial chunks whose variance was between the 25th and 50th percentile of attacker variance (Figure 3B, Panel b), and so on (Figure 3B, Panels c and d). We opted to base this division on attacker variance because in repeated interactions (a) attacker and defender variance tend to mirror one another and (b) defender behavior follows attacker behavior more than vice versa (De Dreu & Gross, 2019b; also see Study 4 here below).

Each participant was shown five unique graphs from each quartile, thus ensuring that the entire range of variability was adequately represented. For each diagram participants predicted the attacker and defender investment on the next, sixth trial. As we knew what the actual investment on the sixth trial was, we could assess to what extent individuals are able to predict attack and defender investments under various levels of cross-round variability. Upon completing the final graph with their predictions for the red and blue players, participants received a short debriefing statement that concluded the experiment.

Results

In total, participants were shown 20 series and made 20 × 2 (attacker/defender) estimates. Estimates were compared to the actual Round-6 investments made by the attacker and defender, giving us both an accuracy score (1 = correct; 0 = incorrect) and a prediction error (actual investment − predicted investment). Analyses showed that when predicting the sixth investment in attack and defense, predictions were incorrect in 75% and 77% of the cases for attack and defense, respectively (Figure 4A).

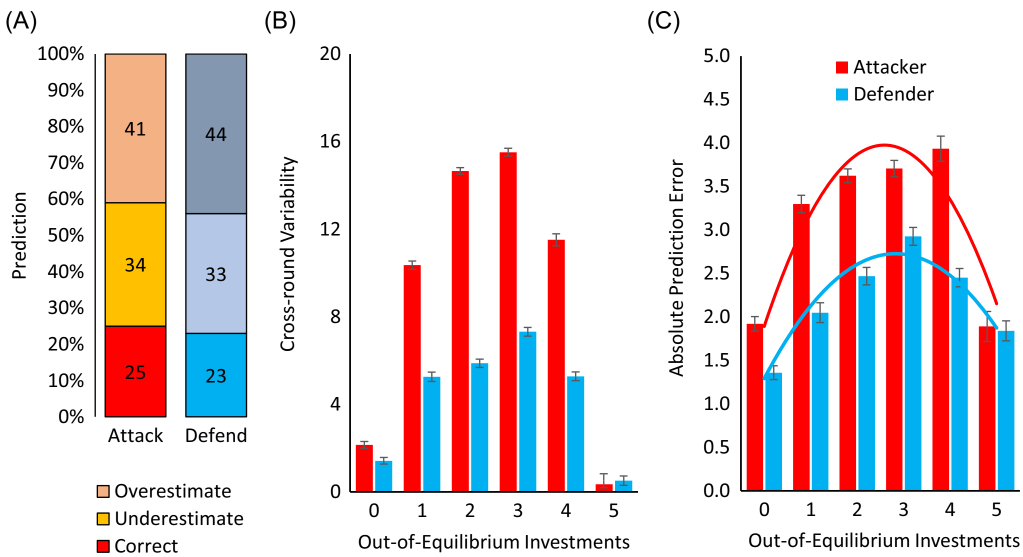
The five-round sequences shown to participants were, for each participant, a random selection from the actual five-round sequences observed in the repeated-interaction experiments included in Study 1. Recall that we observed in Study 1 not only significant variability but also nontrivial amounts of out-of-equilibrium investment in both attack and defense. As a result, also in the stimuli used in Study 2, both attacker and defender invested out-of-equilibrium. Figure 4B shows, as can be expected, that scenarios with intermediate numbers of out-of-equilibrium investment in attack and defense also had greater cross-round variability than scenarios in which attacker or defender always or never invested out-of-equilibrium.

This emerging property of our stimulus materials allowed to explore how out-of-equilibrium investments contribute to unpredictability. We built multilevel regression models with as dependent variable absolute prediction errors (|predicted − actual investment|), and expected investment in conflict. Role, cross-round variability, number of out-of-equilibrium investments, and their interactions served as predictor variables. To examine whether occasional rather than (in)frequent out-of-equilibrium investment not only adds to cross-round variability, as shown in Figure 4B, but also to unpredictability, we added the squared number of out-of equilibrium investments as a final predictor.

Results are summarized in Table 5. Overall, participants expected higher investment in conflict than were actually made (actual − predicted investment: $M = -0.367$, $t = -8.773$, $p < .001$). Participants also expected lower investment in attack than in defense, mimicking the actual behavior of attackers and defenders in Study 1 ($b = -0.690$, $t = -5.634$, $p < .001$). Higher investments in conflict were expected when players were less variable ($b = -0.051$, $t = -4.516$, $p < .001$), and invested more often out-of-equilibrium ($b = 1.167$, $t = 11.416$, $p < .001$), the latter especially for investment in attack (Role × Out-of-Equilibrium, $b = 0.841$, $t = 5.202$, $p < .001$). Finally, participants predicted higher investment when attackers occasionally rather than (in)frequently invested out-of-equilibrium (main effect $b = -0.066$, $t = -3.142$, $p = .002$; interaction with role: $b = -0.141$, $t = -4.172$, $p < .001$).

Table 5 also summarizes results for absolute prediction errors. Prediction was less accurate for next-round attack than defense

Figure 4
Predicting Next-Round Investment in Attack and Defense



Note. (A) Proportion of (in)accurate prediction of 6th round investments by attacker and defender, shown are total ratio of all participant decisions that were correct (lowest), underestimated (middle), or overestimated (highest). (B) Cross-round variability is larger with occasional rather than (in)frequent out-of-equilibrium investment in attack (red bars) and defense (blue bars). (C) Prediction inaccuracy increases when out-of-equilibrium investment in attack and defense emerge occasionally rather than (in)frequent (lines show best-fitting curvilinear regression). See the online article for the color version of this figure.

($b = 0.527$, $t = 4.860$, $p < .001$), and the more variable cross-trial investment was ($b = 0.085$, $t = 8.534$, $p < .001$). Over and beyond these main effects, we also found that prediction accuracy scaled to out-of-equilibrium investments in an inverted *U*-shape manner ($b = -0.098$, $t = -5.268$, $p < .001$). As shown in Figure 4C, absolute prediction errors were larger when out-of-equilibrium investment in conflict occurred occasionally rather than (in)frequently.

Table 5
Absolute Prediction Errors and Expected Investment in Conflict as a Function of Observed Variability and Number of Out-of-Equilibrium Investments for Attack and Defense (Study 2)

Predictor	Absolute prediction error		Expected investment	
	B	*SE*	*B*	*SE*
Role	0.527***	0.108	−0.690***	0.123
Variability	0.085***	0.010	−0.051***	0.011
Out-of equilibrium	0.607***	0.090	1.167***	0.102
Role × Variability	0.026*	0.012	−0.021	0.014
Role × Out-of-Equilibrium	−0.367**	0.143	0.843***	0.162
Out-of-equilibrium (squared)	−0.098***	0.019	−0.066**	0.021
Role × Out-of-Equilibrium (squared)	0.064*	0.030	−0.141***	0.034

Note. Role is dummy coded with 1 = attacker; 0 = defender; Estimates based on multilevel regressions with 8,000 observations nested in 200 participants and 2 × 20 decisions (random intercepts for participant and decision blocks not shown). *SE* = standard error.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Study 3

Findings thus far show that individuals can be variable in their conflict investments both across contests with different partners and across repeated interactions with the same partner. This variability appeared mainly nonsystematic (or at least not captured by a simple functional form such as strictly increasing or decreasing investments over consecutive rounds) and to some degree due to occasional out-of-equilibrium investment in conflict. Both variability and out-of-equilibrium investments made competitors difficult to predict, yet also reduced rather than increased individual payoffs. Rather, variability increased the likelihood of victory among attackers (and of defeat among defenders).

One possible explanation for the pattern of results from Studies 1 and 2 is that (unpredictable) variability is produced by the competitive desire to win the conflict "no matter what" (Dechenaux et al., 2015; Malhotra, 2010). Such motivation may lead to occasional out-of-equilibrium investments in attack that render competitors unpredictably variable and likely to win at significant welfare cost. If true, we should see variability alongside nontrivial frequency of extreme, out-of-equilibrium investment in attack especially in individuals that are biologically and psychologically predisposed to such "winning-at-all-cost" motivation. Studies 3 and 4 focused on this possibility, building on extant work showing that competitive motivation and a desire to "come out ahead" associates with endogenous levels of the steroid hormone testosterone.

In humans, testosterone is secreted in the adrenal cortex, the testicles of males and, to a lesser extent, the ovaries of females (Mazur & Booth, 1998). Testosterone has a well-known and important role in the development of secondary sexual attributes such as increased muscle and bone mass and shapes conflict and competition in a bidirectional manner (Coates et al., 2010; Eisenegger et al., 2011). On the one hand, engaging in competitions for status and resources can release testosterone in both males and females (for reviews, see e.g., Carré & Olmstead, 2015; Casto & Edwards, 2016). On the other hand, elevated levels of testosterone cause individuals to take risks (Apicella et al., 2008; Coates & Herbert, 2008; Stanton et al., 2011) and to more aggressively engage in competitions and status contests (Eisenegger et al., 2011; Geniole et al., 2020; Mehta et al., 2008). For example, participants treated with testosterone (vs. placebo) more aggressively respond to provocation (Dreher et al., 2016), are more distrusting (Boksem et al., 2013; Bos et al., 2010), and have stronger status-seeking motivation (Vermeer et al., 2020). We expected that individuals with higher levels of testosterone more likely exhibit a winning-at-all-cost motivation and therefore make extreme and variable investments in conflict.

To test the possibility that precontest testosterone predicts variability and extremity in conflict, and attack in particular, participants drooled saliva prior to engaging in the contest. From their saliva samples we extracted endogenous testosterone levels and, additionally, cortisol—a glucocorticoid hormone produced in and released by the adrenal glands especially following exposure to stressors (McEwen, 1998). There is some evidence that cortisol buffers the effects of testosterone on aggressive competition and status seeking (viz., dual-hormone hypothesis; e.g., Casto & Edwards, 2016; Knight et al., 2022; Mehta & Josephs, 2010; see Grebe et al., 2019 for a critical assessment of this literature). For example, a recent meta-analysis revealed a small but significant interaction between testosterone and cortisol on status-relevant behavior ($r = -.061$, $p = .026$; Dekkers et al., 2019). We thus explored whether testosterone predicts attacker variability and out-of-equilibrium investment especially when individuals have lower rather than higher levels of baseline cortisol.

Method

Sample and Ethics

With an expected medium effect size (f = 0.40) for overall investment in attack versus defense, 28 subjects were needed to achieve a power of $1 - \beta = 0.80$ (with $\alpha = .05$), a number fitting earlier studies on the relationship between testosterone and social decision making (e.g., Mehta & Josephs, 2010). We thus recruited 28 healthy males (age range 18–43) for an experiment that consisted of two sessions with 7–10 days apart. In Session 1, participants invested as attacker (or defender) and in Session 2 invested as defender (or attacker). One participant failed to show up for the second session, leaving a final sample size of N = 27 males.

The study was fully incentivized, did not involve deception, was approved by the (WOP-2015-4311) and adhered to the Helsinki Protocols for research with humans. We only included participants who indicated they had no current or past neurological or psychiatric diseases and had not taken (prescribed) psychotropic drugs within the past 2 weeks. All experimental sessions were performed between 9:30 and 11:30 in the morning.

Experimental Procedures

Upon arrival in the laboratory, participants were seated in an individual cubicle equipped with a network-connected computer and, after they provided written informed consent, asked to relax and fill out a series of surveys about neutral topics and their lifestyle (survey responses were stored but not analyzed). After 20 min of habituation, the experimenter handed participants a 25 ml sterile polypropylene tube and asked them to swallow all saliva in their mouths and then allow saliva to collect for 3 min, spitting once a minute, for a total of >3 ml of saliva. Collected samples were put on ice immediately and within an hour stored at −18 °C, until transported and analyzed at the Medical Center of the University of Utrecht.

Upon collection of the saliva samples the experimenter unlocked the computer to present participants with the instructions for the attacker–defender contest and a short comprehension test. Participants read that they would make decisions involving themselves and, on each decision trial, an unknown other player that was randomly selected from a pool of other participants. Unbeknown to participants, this pool of decisions consisted of 120 participants making 60 decisions as attacker and 60 as defender in the exact same setup as used here (i.e., 7,200 incentivized investments in attack and 7,200 investments in defense), and dynamically changed as the decisions of the current participants were added to the pool. Thus, each trial was with a new counterpart and trial outcomes were based on real decisions by both attackers and defenders. In Session 1, half of the participants decided in the role of attacker (labeled Role A) and paired on each trial to a new partner in the role of defender (labeled Role B). The other half decided in the role of defender (labeled Role B) and on each trial paired to a new partner in the role of attacker (labeled Role A). Thus, participants made sixty "one-shot" contest decisions. Roles reversed in Session 2, which started with a summary of the attacker–defender contest, and then proceeded with decision making. For 25 out of the 27 participants, we were able to schedule their second session on the same weekday and timeslot as their first session.

In each session, participants made 60 investment decisions as attacker or as defender. On each trial, subjects decided how much to invest (out of €10 endowment) by clicking on numbers between 0 and 10 displayed in a clocklike circle on their computer screen. After each trial, the subject was shown how much the other person for that trial had invested, and their earnings for that trial. If the attacker invested more than its defender, the attacker earned what the defender had not invested and this was added to the attacker's own leftover; if the attacker invested equal or less than its defender, both attacker and defender earned their leftover. The task took approximately 30 min to complete.

Measures

From the 60 investments, we derived the average overall investment (range 0–10), and the cross-round variability (v) in investments, and the proportion of out-of-equilibrium investments. From the saliva collected at the start and ending of each session, testosterone and cortisol were extracted at the endocrinology laboratory at Utrecht University Medical Center, with analysts being blind to the study goals and hypotheses.

Precontest cortisol averaged at $M \pm SE = 10.722 \pm 0.748$ nmol/L for sessions in which participant invested as attacker and 10.593 ± 0.686 nmol/L for sessions in which they acted as defenders and neither differed between roles or time of measurement (all $F < 1$). Precontest testosterone averaged at $M \pm SE = 290.33 \pm 14.974$ pmol/L during attack and 302.148 ± 12.606 pmol/L during defense. Role and time of measurement did not influence testosterone levels (all $F < 1$). For our analyses and to interpret statistical interaction effects, we standardized log-transformed values of cortisol and testosterone. Exploratory analyses detected no statistical outliers (at 3 $SD \pm M$) and all data were used in the final analyses.

Results

Replicating our earlier findings, variability across trials was greater during attack than defense, $t(26) = 2.321$, $p = .028$, $\eta^2 = 0.172$; and individuals more often made out-of-equilibrium investments in attack than in defense, $t(26) = 3.031$, $p = .005$, $\eta^2 = 0.261$. Also, as predicted, individuals invested less in attack than defense but this effect was not significant (n.s.), $t(26) = 1.797$, $p = .084$, $\eta^2 = 0.110$.

To relate contest behavior to precontest testosterone, we built regression models separately for attack and defense using a three-step procedure. In Model 1 (or Step 1), we included (standardized) testosterone. Model 2 (or Step 2) included both testosterone and cortisol as predictors, and Model 3 (or Step 3) added the Testosterone × Cortisol interaction. Model 1 is thus directly aimed at testing our main hypothesis that especially attackers with higher levels of testosterone would show more variable mixing of conflict investment. Models 2 and 3 were included to explore the dual-hormone hypothesis that effects of testosterone emerge especially at lower levels of precontest cortisol.

Table 6 summarizes results. Focusing on Model 1 results, we see that testosterone is unrelated to overall investment in attack and negatively related to overall investment in defense. For variability in investment, we see that precontest testosterone associated with greater variability in attack, but not with variability in defense. This pattern of results remains when including cortisol (Model 2) and the Testosterone × Cortisol interaction (Model 3). The same applies to out-of-equilibrium investments. Precontest testosterone is positively associated with extreme investments during attack, but not defense (Model 1 in Table 6).

Results for Models 2 and 3 additionally showed that cortisol negatively associated with extreme investment in defense, and for attacker variability and out-of-equilibrium investment, we observed significant Testosterone × Cortisol effects (Model 3 in Table 6). Testosterone effects were stronger when cortisol was higher (rather than weaker, as predicted under the dual-hormone hypothesis; we return to this after having reported Study 4).

Study 4

Results from Study 3 resonate with earlier work showing that higher levels of testosterone associate with aggressiveness during resource and status competitions (Boksem et al., 2013; Bos et al., 2010; Dreher et al., 2016; Eisenegger et al., 2011; Geniole et al., 2020; Mehta et al., 2008; Vermeer et al., 2020). To this literature, we add that precontest testosterone also predicts more variability and out-of-equilibrium investment in attack, but not in defense. This fits our hypothesis that attacker unpredictability resides in a

Table 6
Conflict as a Function of (Standardized) Precontest Cortisol, Testosterone, and Their Interaction for Attack and Defense (Study 3)

Predictor	Model 1		Model 2		Model 3	
	B	*SE*	*B*	*SE*	*B*	*SE*
Attacker conflict investment						
Testosterone (T)	−0.160	0.408	−0.112	0.505	−0.182	0.516
Cortisol (C)			−0.083	0.505	−0.074	0.569
T × C					0.105	0.369
Defender conflict investment						
Testosterone (T)	−0.289**	0.131	−0.166	0.170	−0.646	0.757
Cortisol (C)			−0.191	0.170	−0.141	0.188
T × C					0.207	0.318
Attacker conflict variability						
Testosterone (T)	1.414**	0.562	1.330*	0.694	0.424	0.645
Cortisol (C)			0.149	0.694	0.267	0.585
T × C					1.382**	0.419
Defender conflict variability						
Testosterone (T)	0.272	0.533	0.578	0.702	3.266	3.108
Cortisol (C)			−0.476	0.702	−0.756	0.772
T × C					−1.161	1.307
Attacker out-of-equilibrium						
Testosterone (T)	0.777**	0.282	0.799**	0.349	0.290	0.304
Cortisol (C)			−0.040	0.394	0.027	0.276
T × C					0.778**	0.197
Defender out-of-equilibrium						
Testosterone (T)	−0.018	0.028	0.040	0.033	−0.051	0.148
Cortisol (C)			−0.09**	0.030	−0.080**	0.037
T × C					0.039	0.062

Note. Cortisol and testosterone are standardized with $M = 0$ and $SD = 1.0$. SE = standard error.
* $p < .05$. ** $p < .025$ (with $N = 27$).

"winning-at-all-cost" motivation, a motivation presumably stronger in individuals with higher levels of testosterone.

In Study 4, we again examined the relation between precontest testosterone (and cortisol) and variability and extremity in attacker–defender conflict behavior. Whereas Study 3 used a random-partner matching protocol and an all-male sample, Study 4 included both male and female participants and had dyads fixed in a 90-round attack–defense contest. This allowed us to examine in detail and over time the action–reaction dynamics at both the neurocognitive and behavioral level. Earlier work already showed that average investment in defense tracks attacker investment more than the other way around (De Dreu & Gross, 2019b). This fits the idea that attack is more instrumental and proactive and defense more reactive and "impulsive" (Nelson & Trainor, 2007; Wrangham, 2018). In essence, defenders follow and react more to what attackers do, while attackers have greater initiative. At the behavioral level, we would thus expect that variability in defense follows variability in attack more than vice versa.

A similar asymmetry can be expected at the neurocognitive level, and in particular for sympathetic arousal. Sympathetic arousal refers to the release of the neurohormone norepinephrine and subsequent physiological changes including accelerated heart rate and restricted preejection period (PEP; McEwen, 1998; also see Blascovich et al., 2004; Jonas et al., 2014; Mendes et al., 2007). PEP is the most direct cardiovascular measure of sympathetic arousal, while heart rate is under the influence of both the sympathetic and parasympathetic nervous system (Brownley et al., 2000). Combined, these physiological changes mobilize the brain and body for a fight-or-flight response to stress and perceived threat (Chida & Hamer, 2008; Lorber, 2004; Murray-Close et al., 2017; also see Kelsey, 2012; Richter et al., 2016). There is some evidence that predatory attack in nonhuman animals is purposeful and goal-directed, whereas reactive and defensive aggression is more "impulsive" and more strongly conditioned by sympathetic arousal (Nelson & Trainor, 2007; Potegal & Nordman, 2023; Weinshenker & Siegel, 2002; Wrangham, 2018). Possibly, variability in conflict investment is less strongly related to sympathetic arousal in attackers than in defenders. Furthermore, unpredictable attackers may be more threatening and arousing than unpredictable defenders. If true, we should see attacker variability to increase sympathetic arousal in defenders more than the other way around.

Method

Research Ethics and Sample Size

The experiment was fully incentivized, did not involve deception and received ethics approval from Leiden University (CEP17-1026/362). Participants were treated in accordance with the Helsinki Protocols for research with humans. Participants indicated that they had no current or past neurological or psychiatric diseases and had not taken (prescribed) psychotropic drugs within the past 2 weeks. To control diurnal fluctuations in hormone secretion, all experimental sessions were performed between 9:30 and 11:30 a.m., and each session lasted approximately 90 min. In addition, participants were instructed and reminded that in the 2 hr before the experimental session, they should not eat (except a light snack), not consume caffeine or alcohol, and not smoke.

Participants gave written informed consent and were debriefed. They received a €6.50 show up fee and the outcome of five randomly selected rounds of decision making (range €1–€14.5; $M =$ €7.40). Sample size was determined at $n = 55$ attacker–defender dyads, based on a power analysis for a multivariate within-dyad repeated measures (90 contests) design with $f = 0.2$, $\alpha = .05$ and $1 - \beta = 0.90$. We recruited 112 participants (79.5% female; age $M = 21$, $SD = 3.05$, range 18–35 years), resulting in 56 attacker–defender dyads. Data files of three dyads were corrupted, leaving $N = 53$ dyads for final analyses.

Experimental Procedures and Measures

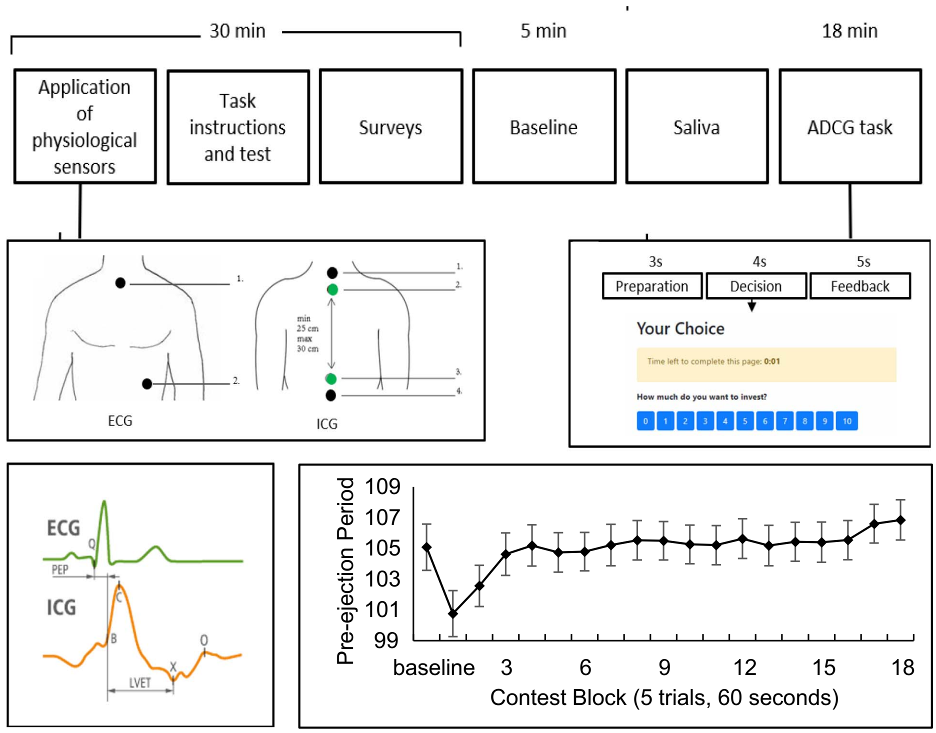
An experimental session consisted of two participants unknown to each other and scheduled to arrive 10 min apart. Participants were seated in individual cubicles, prohibiting them from seeing each other. Participants first filled in their personal information after which physiological electrodes were applied to the body of the participants (Figure 4; also see Blascovich et al., 2011). To ensure that participants' physiological responses were not influenced by unrelated activities performed before the experiment, they had to wait at least 30 min in the lab before recording cardiovascular activity. During this habituation period, participants read instructions for the attacker–defender contest, followed by comprehension questions that ensured their understanding of the task. To fill the remaining time, participants filled out several surveys (data not analyzed).

After the 30-min habituation period, participants were shown peaceful underwater nature scenes for 5 min while baseline cardiovascular responses were recorded. Then participants were given a 25 ml sterile polypropylene tube and asked to swallow all saliva in their mouths and allow saliva to be collected for 3 min, spitting once a minute, for a total of >3 ml of saliva. Tubes were collected immediately and stored on dry ice during the remainder of the session, after which they were placed in a storage freezer at −18° Celsius.

Upon collection of the saliva samples, the experimenter unlocked the participants' computers and participants were presented with the instructions for the attacker–defender contest and a short comprehension test. Participants read that they would make decisions involving themselves and, on each decision trial, the other player currently present with whom they were paired. Within each dyad, one participant was randomly assigned to the role of "attacker" (labeled as Role A) while the other participant was assigned the role of a "defender" (labeled as Role B). On each trial, participants had to decide how much to invest (out of their €10 endowment). After each trial, the participants were shown how much the other person for that trial had invested and their earnings for that trial. If the attacker invested more than its defender, the attacker earned what the defender had not invested and this was added to the attacker's own left over (the defender earned 0, respectively); if the attacker invested equal or less than its defender, both attacker and defender earned their left over.

The contest involved 90 rounds of decision making, and to accommodate physiological measurement, each decision round lasted exactly 12 s (Figure 5). Specifically, participants were first presented with a screen that prompted them to prepare their decision. After 3 s, participants were shown the investment screen and were given 5 s to select their investment by clicking on one of 10 buttons shown in a row on the screen numbered from 0 to 10. Making a

Figure 5
Experimental Timeline and Measurements



Note. After application of physiological sensors, a baseline physiology measure, and a saliva sample, participants engaged in the attacker–defender contest game (ADCG, top panel); placement of electrodes (left middle panel): For electrocardiography (ECG), we used two spot electrodes: on the manubrium (1) and on the left lower costal margin (2; left). For impedance cardiography (ICG), we used four spot electrodes: five centimeters higher than the base of the neck (1), at the base of the neck (2), 30 centimeters below the base of the neck (3), and 33 centimeters below the base of the neck (4; right). Electrodes 1 and 4 emitted a high-frequency alternating current of 400 µA and Electrodes 2 and 3 detected the voltage flowing through the thorax; examples of ECG and ICG waveforms are shown in the left bottom. The interval between the Q-point and the B-point marks the preejection period (PEP, and LVET, left ventricular ejection time). Right middle panel shows the timeline of one contest round; right lower panel shows the average preejection period at baseline and for each five-trial contest block participants engaged in. See the online article for the color version of this figure.

selection would register their investment and take them to the feedback screen. If the participant failed to choose an investment within 5 s, the computer would generate a random investment for them, but they would earn 0 on that round. This happened in 1.78% of the trials, and we removed these trials from the analyses. The investment was followed by a feedback screen that lasted a variable amount of time to ensure that each trial took a total of 12 s (specifically, 9 s minus participant's time to make investment). Upon completion of the contest, participants filled out several surveys to complete a lapse of 30 min after the first saliva sample. Participants filled a second tube with >3 ml of saliva and received a written debriefing.

Measures and Data Preprocessing

Saliva samples were assayed for testosterone and cortisol at the neuroendocrinology laboratory at the Free University Amsterdam. Cortisol and testosterone were standardized within genders (Stanton et al., 2021). The level of (log-transformed) cortisol detected at baseline was lower post contest (M_{change} = −0.284, 95% CI [−0.337, −0.232]); the within-genders standardized level of testosterone detected at baseline was about the same as post contest (M_{change} = 0.041; 95% CI [−0.054, 0.137]). At baseline, cortisol and testosterone were not correlated, $r(53) = 0.233$, $p = .109$ for attackers and $r(53) = 0.145$, $p = .302$ for defenders; post contest, these correlations were $r = 0.149$ ($p = .288$) and $r = 0.153$ ($p = .275$), respectively. Exploratory analyses detected no statistical outliers (at 3 $SD \pm M$) in our data. Twenty-eight percent of the females indicated they used hormonal contraception, yet this variable did not affect the detected level of precontest testosterone or cortisol detected ($t < 1$). In addition, among our female participants, we found no correlations between precontest testosterone and cortisol on the one hand, and self-reported days since last menstruation (all $r < 0.20$, $ps > .15$). Both variables are further ignored, and for all analyses involving hormonal indicators we only controlled for participant age and gender (Stanton et al., 2021).

To obtain measures of sympathetic arousal, we continuously measured electrocardiography and impedance cardiography (see

Figure 5) using a Biopac MP150 system. Electrocardiography and impedance cardiography data were stored used Acqknowledge software (Biopac Systems Inc., Goleta, California, USA) and scored with the PhysioData Toolbox software (Sjak-Shie, 2019). Segments of movement artifacts were removed, and the impedance cardiography and electrocardiography signals were ensemble-averaged across 1-min epochs yielding one epoch for baseline and 18 epochs for the contest blocks for each participant. The Q-point (Berntson et al., 2004), C-Point, X-point, and B-point (Sherwood et al., 1990) were automatically scored by the software (yielding one PEP value per epoch) and then manually checked. A 2 (role: attacker vs. defender) × 19 (block: baseline vs. Block 1 vs. … Block 18) mixed-model analysis of variance with role within-dyads and block as a within-subjects repeated measure only revealed a main effect for block, $F(1, 52) = 6.970$, $p = .011$. Effects for role and Role × Block were not significant, $F < 1$. For both attacker and defender, engaging in the contest was initially arousing, with PEP reducing between baseline and the first contest block for defenders from $M = 106.887$ to $M = 101.613$; $t(52) = 4.388$, $p < .001$, and for attackers from $M = 103.283$ to $M = 99.915$, $t(52) = 2.219$, $p = .031$ (recall that lower values for PEP indicate higher sympathetic arousal). As can be seen in Figure 5 (bottom right panel), however, by the fourth block sympathetic arousal was back to precontest baselines and remained relatively stable thereafter.

Finally, from the investment decisions, we derived the overall investment (range 0–10) and the cross-round variability in investments. We also computed earnings and the percentage of attacker victories. To relate behavior to sympathetic arousal, we binned investment and variability across the five trials in each block for which we had a measure of sympathetic arousal.

Results

As in Study 1 (Tables 1 and 2), participants in Study 4 invested less in attack than in defense ($t = 21.673$, $p < .001$) and were more variable in their investments during attack than defense ($t = 5.74$, $p < .01$). Extreme, out-of-equilibrium investments were frequently seen during both attack and defense (proportion out of 90 trials: 0.297 and 0.377, respectively), with no difference between them ($t < 1$, not significant). We already showed in Table 2 that attacker variability is associated with attacker victory ($r = 0.404$, $p < .001$). In addition, although not significant, the more variable defenders were, the more often they were defeated by their attackers, $r(53) = 0.229$, $p = .099$. Finally, the more variable defenders were, the more their attackers earned, $r(53) = 0.337$, $p = .014$.

Moderation by Testosterone

To examine conflict behavior as a function of precontest testosterone, we computed regression models separately for attack and defense, with precontest testosterone, cortisol, and their interaction as predictors. Participant age and gender were entered as control variables. To account for the interdependency in the dyadic data we partialled out defender behavior when examining attackers, and vice versa (e.g., when estimating attacker investments, we included defender investment as a covariate). As in Study 3, and for each criterion (average conflict investment, variability, and out-of-equilibrium investment), we estimated three models. Model 1 included standardized precontest testosterone, Model 2 added standardized precontest cortisol, and Model 3 further included the Testosterone × Cortisol interaction. As in Study 3, Model 1 was our main focus.

Results are summarized in Table 7. Replicating Study 3, neither average investment in attack nor in defense was conditioned by precontest testosterone (or cortisol; top panel in Table 7). Also as in Study 3, and in all three models, higher levels of precontest testosterone were associated with more variability in attack but not in defense (Figure 6A). Again, neither cortisol nor the Testosterone × Cortisol interaction reached significance (middle panels in Table 7). Finally, in contrast to Study 3, we find no evidence for a link between testosterone and extreme (out-of-equilibrium) investment in attack and defense (bottom panel in Table 7).

Sympathetic Arousal and Conflict Behavior

To explore how conflict dynamics shape and are shaped by sympathetic arousal, we built lagged-panel regression models with PEP as a marker of sympathetic arousal. As before, to account for the interdependency in the dyadic data, we partialled out defender behavior when examining attackers, and vice versa (e.g., when estimating attacker investments, we included defender investment as a covariate). Regression models and results are summarized in Table 8.

We first estimated attacker (defender) arousal as a function of their previous block investments in conflict. Specifically, we regressed attacker's (defender's) PEP in block$_{(x)}$ onto their PEP in block$_{(x-1)}$, their own attacker (defender) investment and variability therein in block$_{(x-1)}$, and their defender's (attacker's) investment and variability in block$_{(x-1)}$. For attackers, the overall regression model was significant, $F(6, 45) = 3.147$, $p = .012$. Attacker arousal was higher when their defender displayed more variability in their investment in the previous block, $b = -3.016$, $t = -3.014$, $p = .004$ (Table 8). Conversely, we do not find this effect for defender arousal. The overall regression model is not significant, $F(6, 45) = 1.709$, $p = .141$, and neither attacker nor defender behavior associated with PEP.

Second, we estimated attacker's (defender's) conflict investment as a function of their previous block sympathetic arousal. Specifically, we regressed attacker's (defender's) investment in block$_{(x)}$ onto their PEP, attacker (defender) own investment and variability, and their opponent's (defender's or attacker's) investment and variability in block$_{(x-1)}$. For attacker's investment in conflict, the overall regression model was not significant, $F(7, 44) = 1.930$, $p = .087$. Attacker's investments were nonsignificantly higher the more they invested in the previous block, $b = 0.378$, $t = 1.756$, $p = .086$, and significantly lower the more their defenders invested in the previous block, $b = -0.623$, $t = -2.643$, $p = .011$. For defender investment in conflict, the overall regression was significant, $F(7, 44) = 2.379$, $p = .037$, yet no single predictor emerged as significant (Table 8).

Finally, we estimated attacker (defender) conflict variability as a function of attacker's (defender's) sympathetic arousal. Specifically, we regressed attacker's (defender's) variability in block$_{(x)}$ onto their PEP, attacker (defender) own investment and variability, and their opponent's (defender's or attacker's) investment and variability in block$_{(x-1)}$. For attackers, the overall regression model was not significant, $F(7, 44) = 0.321$, $p = .940$, nor was any single predictor. For defenders, however, the overall regression was significant, $F(7, 44) = 2.842$, $p = .016$: Defender variability was a

Table 7
Regression of Testosterone and Cortisol on Variability in Attacker and Defender Conflict Investment (Top), Variability in Investment (Middle), and Out-of-Equilibrium Investment (Bottom; Study 4)

Predictor	Model 1		Model 2		Model 3	
	B	*SE*	*B*	*SE*	*B*	*SE*
Attacker investment						
Gender	0.010	0.414	0.199	0.435	0.117	0.439
Age	0.101	0.063	0.111	0.063	0.107	0.063
Defender investment	0.862***	0.100	0.846***	0.099	0.839***	0.099
Testosterone	−0.144	0.222	−0.209	0.225	−0.097	0.244
Cortisol			0.231	0.173	0.140	0.190
Testosterone × Cortisol					−0.327	0.284
Defender investment						
Gender	0.762**	0.336	0.819**	0.342	0.786**	0.347
Age	0.021	0.042	0.023	0.042	0.020	0.042
Attacker investment	0.702***	0.083	0.688***	0.085	0.693***	0.085
Testosterone	−0.182	0.192	−0.215	0.195	−0.207	0.197
Cortisol			0.139	0.149	0.100	0.159
Testosterone × Cortisol					0.114	0.163
Attacker variability						
Gender	−1.411	1.189	−2.069	1.270	−2.172	1.301
Age	−0.325	0.184	−0.375*	0.186	−0.382*	0.188
Defender variability	1.010***	0.162	0.969***	0.164	0.960***	0.166
Testosterone	1.794***	0.649	1.977***	0.656	2.103***	0.719
Cortisol			−0.705	0.508	−0.817	0.570
Testosterone × Cortisol					−0.377	0.841
Defender variability						
Gender	0.244	0.789	0.085	0.813	−0.075	0.805
Age	−0.022	0.094	−0.026	0.095	−0.042	0.094
Attacker variability	0.396***	0.072	0.408***	0.073	0.407***	0.072
Testosterone	0.336	0.418	0.378	0.422	0.398	0.415
Cortisol			−0.284	0.337	−0.471	0.350
Testosterone × Cortisol					0.583	0.358
Attacker O-E						
Gender	−0.019	0.056	0.007	0.059	−0.013	0.059
Age	0.012	0.009	0.013	0.009	0.012	0.008
Defender O-E	0.753***	0.095	0.750***	0.094	0.730***	0.093
Testosterone	−0.007	0.029	−0.016	0.030	0.008	0.032
Cortisol			0.030	0.023	0.011	0.024
Testosterone × Cortisol					−0.069	0.037
Defender O-E						
Gender	0.103**	0.051	0.105	0.052	0.101	0.053
Age	0.002	0.006	0.002	0.006	0.001	0.006
Attacker O-E	0.775***	0.097	0.772***	0.100	0.774***	0.101
Testosterone	−0.010	0.029	−0.011	0.029	−0.010	0.030
Cortisol			0.003	0.023	−0.001	0.024
Testosterone × Cortisol					0.012	0.025

Note. Gender is dummy coded with 0 = male, 1 = female; Cortisol and testosterone are standardized with $M = 0$ and $SD = 1.0$. *SE* = standard error; O-E = out-of-equilibrium.
$^{*}p < .010$. $^{**}p < .05$. $^{***}p < .01$ (with $N = 53$).

function of both their own and their attacker's sympathetic arousal in the previous block, $b = -0.65$, $t = -2.392$, $p = .021$, and $b = -0.078$, $t = -3.301$, $p = .002$ (Figure 6C, and Table 8). Put differently, the more sympathetic arousal attackers and defenders had in the previous block, the more variable defense investments were subsequently.

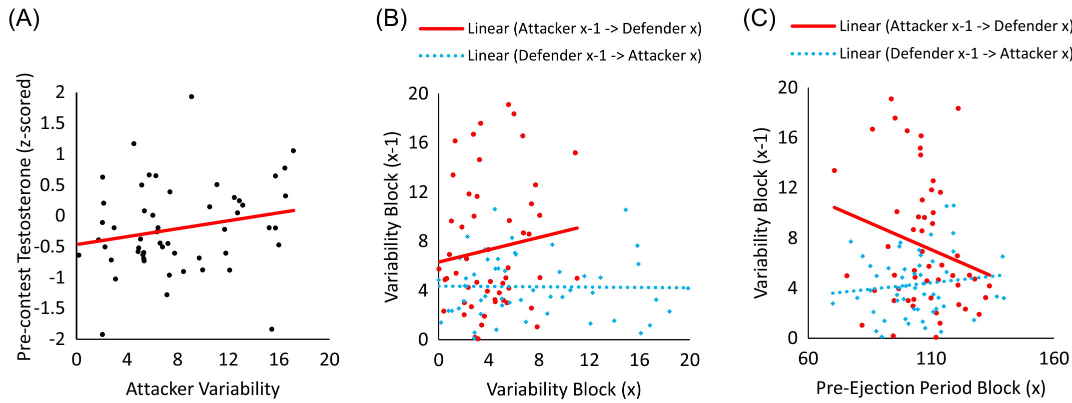
Discussion

Results of Study 4 combined suggest that (a) attackers are more variable when their precontest testosterone levels are higher (Figure 6A and Table 7), and (b) the more variable attacker investments are, the more variable defenders are in their response (Figure 6B, and Table 7). More variable attacker behavior (c) increases sympathetic arousal in defenders (Figure 6C, and Table 8) which, in turn, (d) associates with increased variability in defense (Table 8). Variability in defenders thus emerges as a function of their sympathetic arousal in response to attacker's variability. Finally, (e) the more variable defenders were, the more often they were defeated by their attackers and the more their attackers earned. This suggests that the arousal-induced variability in defenders helps attackers to settle conflict in their favor.

Together these results from Study 4 add three insights to our earlier studies. First, we replicated that precontest testosterone

Figure 6

Testosterone and Sympathetic Arousal Shape and Are Shaped by Conflict Dynamics



Note. (A) Higher levels of precontest testosterone in attackers associate with more variability in conflict investment; (B) attacker variability predicts subsequent variability in defense better than the other way around; (C) higher variability in attackers predicts more sympathetic arousal (i.e., lower preejection periods) in defenders. Scatterplots show individual pairings (red dots = attackers; blue diamonds = defenders) with best-fitting linear regression lines inserted (solid = attack predicting defense; dashed = defense predicting attack). See the online article for the color version of this figure.

predicts how variable attackers but not defenders are. This finding resonates with our hypothesis that an increased motivation to "win-at-all-cost" underlies unpredictably variable behavior, particularly for attacks. We return to this in the General Conclusions and Discussion. Note that in some earlier work, effects of testosterone on aggression and competitiveness emerged especially under lower levels of basal cortisol (viz., dual-hormone hypothesis; Casto & Edwards, 2016; Mehta & Josephs, 2010). In our studies, we did not observe this. In Study 3 we found, in some analyses, an interaction between testosterone and cortisol but not in the form expected under the dual-hormone hypothesis. In Study 4, we never observed significant Testosterone × Cortisol interactions. As such, current results align and add to the conclusion from recent meta-analyses that evidence for the dual-hormone hypothesis is limited to specific cases (Dekkers et al., 2019) and potentially problematic (Grebe et al., 2019). As our studies were not designed to test the dual-hormone hypothesis in the context of attacker–defender contests, we refrain from further interpretation of these null results.

Our second insight from Study 4 is that, in fixed-partner protocols, defenders respond, both in their overall investment and in their variability to their attacker's initiatives—the more variable attacker's investments are, the more variable the defenders become. Crucially, we obtained some evidence that attacker variability increases sympathetic arousal in defenders, and that defender arousal predicts how variable their investments subsequently are. Because defender variability associates with a higher likelihood of being defeated, these results point to a possible pathway from attacker variability, through sympathetic arousal in their defenders, to attacker successes in defeating their defenders.

Conclusions and General Discussion

Conflict theory anticipates that, in some situations, individuals may be motivated to be unpredictable and can be expected to vary whether and how much they invest in conflict. Our review of the empirical literatures in experimental economics and psychological

Table 8

Sympathetic Arousal and Conflict Dynamics (Study 4)

	Defender block$_{(x)}$						Attacker block$_{(x)}$					
	Arousal		Investment		Variability		Arousal		Investment		Variability	
Predictor	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Gender	7.16**	4.776	−1.016^	0.596	2.445**	0.874	12.752**	4.469	0.408	0.645	0.054	2.077
Att. inv.$_{(x-1)}$	0.885	1.534	0.194	0.203	0.271	0.298	−1.557	1.568	0.378^	0.215	−0.576	0.692
Att. var.$_{(x-1)}$	0.076	0.505	−0.003	0.064	−0.034	0.094	0.718	0.506	−0.046	0.070	−0.018	0.226
Def inv.$_{(x-1)}$	−2.455	1.633	−0.342	0.223	−0.168	0.327	1.842	1.686	−0.623**	0.236	0.468	0.759
Def. var.$_{(x-1)}$	−1.018	0.965	0.190	0.127	0.143	0.186	−3.016**	1.001	0.208	0.139	−0.002	0.449
Att. arousal$_{(x-1)}$	NA	NA	0.015	0.016	−0.065**	0.027	0.092	0.125	−0.001	0.018	−0.057	0.059
Def. arousal$_{(x-1)}$	−0.109	0.130	−0.031^	0.018	−0.078**	0.024	NA	NA	−0.029	0.019	−0.062	0.062

Note. Gender is dummy coded with 1 (0) = female (male); arousal is proxied by preejection period, with lower scores indicating more sympathetic arousal. *SE* = standard error; (*x*) (*x* − 1) = measure in current (previous) block, with one block consisting of five investments rounds of 12 s each; Att. (Def.) inv. = attacker (defender) investments averaged across the five trials in one block; Att. (Def.) var. = attacker (defender) variability in investment across the five trials in one block; NA = not applicable (i.e., this predictor was not entered into the regression model for the specific criterion).
^$p < .10$. ** $p < .01$ (with $N = 52$) .

science revealed three open issues: (a) do people in conflict with its equilibrium in mixed strategies variably mix whether and how much they invest in conflict; (b) does such variable mixing render competitors unpredictable to their counterpart; and (c) how does being (unpredictably) variable influence conflict dynamics and outcomes. In four studies, we addressed these questions in the realm of attacker–defender contests in which one individual invests, as attacker, to win against and exploit an opponent who, in turn, invests to defend against attacks and prevents being exploited.

Findings combined answer the open questions as follows. First, attackers as well as defenders produce significant variation in their conflict investments both when interacting with different opponents and when repeatedly interacting with the same opponent. Second, variability makes conflict parties' next move difficult to predict—variability renders competitors unpredictable, and especially when variability is produced by occasional out-of-equilibrium investment in conflict. Third, being unpredictably variable reduced earnings especially for defenders, and increased the likelihood that attackers successfully defeated their defender. The reason for this is that being unpredictable during attack partly resides in and emerges from a motivation to "win-at-all-cost" and leads attackers to occasionally lash out with extreme investments that are irrational from a payoff-maximizing perspective.

Implications for Theory and Future Research

Findings have several implications for conflict theory. First, agents are often assumed to be rational (expected) payoff maximizers (viz., homo economicus), which simplifies mathematical analyses, makes very few assumptions (parsimony), and can sometimes approximate human behavior well enough. Here, we identified that people may also not only, or not at all, be motivated by earnings per se. Rather, our results suggest that people during attack may be also, or exclusively, motivated to win the contest and emerge victorious "no matter what." Attackers were, accordingly, occasionally investing out-of-equilibrium and while this cannot be understood from a strict payoff-maximizing perspective, such behavior does fit a winning-at-all-cost motivation (Thaler, 1988; van den Bos et al., 2008).

Second, and relatedly, our findings subscribe to the general insight that human preferences are heterogeneous and, possibly, malleable (De Dreu & Gross, 2019a). In both Studies 3 and 4, we found that the utility from winning appeared stronger among individuals with higher levels of precontest testosterone, a steroid hormone associated with risk tolerance, competition, and status seeking (e.g., Coates et al., 2010; Eisenegger et al., 2011; Geniole et al., 2020; Mazur & Booth, 1998). Third, and finally, findings specify Schelling's conjecture that being unpredictable can be strategically advantageous in two ways. First, the advantage resides in attackers and not in the defending party. Second, the advantage is in terms of the ability to win and emerge victorious (viz., relative fitness), and not (only) in the ability to maximize expected payoff (viz., absolute fitness).

Next to contributions to theory on conflict, findings contribute to work on the neurobiology of human aggression. Attacking has been linked to instrumental and proactive aggression that may be premediated and "cool-headed." Defending, in contrast, is a more reactive form of aggression that may be more impulsive and conditioned by sympathetic arousal (Nelson & Trainor, 2007; Potegal & Nordman, 2023; Weinshenker & Siegel, 2002; Wrangham, 2018). Elsewhere, we indeed observed attack decisions to take more time (De Dreu et al., 2015, 2019), and to involve more sophisticated cognitive reasoning (Rojek-Giffin et al., 2020). Here, we can add, from Study 4, that attacker behavior is not, and defender behavior is, a function of (their own) sympathetic arousal. Accordingly, current findings further support the possibility that attacker–defender contests allow for a clean decomposition of instrumental and proactive versus impulse and reactive aggression and help to shed further light on the neurobiological and psychological underpinnings of these distinct forms of human aggression (Sarkar & Wrangham, 2023).

Outside of the domain of conflict and aggression, cognitive science has questioned whether humans can be unpredictable because they have difficulty being random(Burns & Vollmeyer, 1998; Cooper, 2016; Sanderson, 2018; Wagenaar, 1972; Warren et al., 2018; Wong et al., 2021). Our results speak to this issue in two ways. First, we obtained some evidence that conflict strategies are less rather than more systematic and that more variable strategies made competitors difficult to predict. Possibly, at least in conflict and competition, humans can be nonsystematic and unpredictable at least to a degree to which other humans have difficulties predicting their next move. Second, we obtained suggestive evidence that humans can be unpredictably variable at least when this serves strategic considerations—when conflict has its equilibrium in mixed strategies, for example. It would be interesting to further pursue these possibilities and test whether unpredictability is indeed observed more when being unpredictable has fitness functionality rather than not. In addition, our results cannot tell whether unpredictably variable investments in conflict were cognitively controlled and deliberated or instead uncontrolled and intuitive. If the latter would be the case, being unpredictable or not may reflect an evolved capacity with nontrivial fitness relevance.

Study Limitations

Our conclusions and implications need to be considered in light of several limiting factors. First, we studied populations of well-educated adults performing stylized economic contests. We have shown elsewhere that competitive actions in these attacker–defender contests are replicable across cultural contexts, and that investment in attack and defense correlate with self-reported "willingness to fight" from social value survey measures (Romano et al., 2022). Nevertheless, future research is needed to examine to what extent our findings replicate in other conflict games with their equilibrium in mixed strategies such as hide-and-seek games (Bar-Hillel, 2015) and best-shot-weakest link games (Clark & Konrad, 2007). Second, in our studies, individuals only had their counterpart's past behavior to predict the future. Outside stylized games of conflict, however, individuals often invest in obtaining information about their counterpart and incorporate such information in their predictions. For example, governments and private organizations invest in intelligence and counterintelligence to identify targets for military invasions and hostile takeover attempts and to assess the potential aggression from nearby competitors. Ordinary citizens, likewise, install cameras and silent alarms on their front entrance to survey for and preemptively detect potential burglars; burglars in turn investigate estates to identify its weak spots and possibilities for entry and theft. Accordingly, individuals respond to each other's unpredictability in an "arms race" manner between being deliberately unpredictable toward others and deliberately "undoing" another's unpredictability. There is some irony in this, as in the end the investments in intelligence and counterintelligence do not solve the profound advantages of being unpredictable in conflict with mixed-strategy equilibria—when defenders reduce the attacker's ability to be unpredictable, attackers become motivated to improve on their unpredictability, which motivates defenders to invest further in intelligence, and so on.

Coda

High-ranking politicians and military leaders sometimes appear irrational and irreducibly unpredictable. Here, we elucidated why and when such erratic mixing between hostility and amity can be functional in the context of attacker–defender conflicts. Human participants, indeed, showed substantial variation in their behavior, even considering extensively costly actions that allow them to be more unpredictable and victorious at significant welfare cost to both victor and victim. Being unpredictable sometimes serves to win no matter what.

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Correction to "What Limitations Are Reported in Short Articles in Social and Personality Psychology" by Clarke et al. (2023)

The following article is being corrected: Clarke, B., Schiavone, S., & Vazire, S. (2023). What limitations are reported in short articles in social and personality psychology. *Journal of Personality and Social Psychology: Personality Processes and Individual Differences, 125*(4), 874–901. https://doi.org/10.1037/pspp0000458. The percentages in the seventh sentence in the abstract now appear as 41% and 20%, respectively. The online version of this article has been corrected.

https://doi.org/10.1037/pspp0000502