skills — such as visual search [9], adaptations to increase shooting range [4] or ways to learn efficiently [3] — to cope with the apparently few prey items available during the day (Supplemental information).

SUPPLEMENTAL INFORMATION

Supplemental Information including experimental procedures, one figure and five movies can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.06.005.

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[1]Department of Animal Physiology, University of Bayreuth, 95440 Bayreuth, Germany.
*E-mail: stefan.schuster@uni-bayreuth.de

Correspondence

The gambler's fallacy in penalty shootouts

Sebastian Braun[1,*] and Ulrich Schmidt[1,2,*]

A well-known bias in subjective perceptions of chance is the gambler´s fallacy: people typically believe that a streak generated by a series of independent random draws, such as a coin toss, becomes increasingly more likely to break when the streak becomes longer [1]. In a fascinating study, Misirlisoy and Haggard [2] analysed sequential behavior of kickers and goalkeepers in penalty shootouts. They report that goalkeepers are prone to the gambler's fallacy: after a series of three kicks in the same direction, goalkeepers are more likely to dive in the opposite direction at the next kick. Here we argue, first, that a binomial test is more appropriate for testing gambler's fallacy than the tests employed by Misirlisoy and Haggard [2], and second, that penalty shootouts may not be well-suited to analyze the gambler's fallacy. Using a binomial test, we neither find statistically significant evidence for gambler's fallacy in Misirlisoy and Haggard's [2] original data, nor in extended data, nor in data from an idealised laboratory experiment that we ran to address the second point. In line with Misirlisoy and Haggard's [2] original result, we do, however, find evidence for a systematic pattern of goalkeeper's behavior that kickers could exploit.

The dataset of Misirlisoy and Haggard [2] — henceforth referred to as M&H — includes 16 observations where one can observe the goalkeeper's behavior after a series of three consecutive kicks in the same direction. In 11 out of 16 cases, the goalkeeper dived in the direction opposite to the last kick's direction. This observation would constitute evidence in favor of a gambler's fallacy if it would allow us to reject the null hypothesis that

Table 1: Share of goalkeeper dives in the opposite direction to the last kick's direction, by data set

Number of repeated kicks in the same direction	Misirlisoy and Haggard [2]	deltatre	Misirlisoy and Haggard [2] and deltatre	Lab experiment
	(1)	(2)	(3)	(4)
1	0.535	0.542	0.529	0.519
	(0.214)	(0.166)	(0.210)	(0.234)
	[159]	[153]	[221]	[426]
2	0.576	0.531	0.537	0.540
	(0.134)	(0.354)	(0.269)	(0.185)
	[66]	[64]	[95]	[150]
3	0.688	0.556	0.577	0.453
	(0.105)	(0.407)	(0.279)	(0.809)
	[16]	[18]	[26]	[64]
All observations	0.559	0.547	0.542	0.516
	(0.037)**	(0.079)*	(0.062)*	(0.217)
	[247]	[243]	[354]	[653]

Entries give the share of goalkeeper dives in the opposite direction to the last kick's direction following runs of one, two, and three repeated kicks in the same direction. Entries in curly brackets give the p-values of an exact one-sided binomial test (H0: $p = 0.5$ vs. H1: $p > 0.5$), entries in squared brackets give the number of observations in each cell. Columns 1 and 2 use data by Misirlisoy and Haggard [2] and deltatre, respectively. Column 3 adds data from deltatre on the Champions League and the World Championship 2014 to the data by Misirlisoy and Haggard [2]. Column (4) uses data from the lab experiment.

the goalkeeper's dive direction is a sequence of independent Bernoulli trials with a probability of 0.5 for either (opposite or same) direction [3]. The appropriate test for this null, a binomial test, does not allow one to reject the null at the 21% significance level (two-sided test) or 10.5% significance level (one-sided test). More generally, we cannot reject the null after series of one, two or three repeated kicks in the same direction (see column 1 of Table 1). In contrast to us, M&H used bootstrap hypothesis testing; however, it remains unclear which null hypothesis M&H are actually testing with this method and whether their resampling, as required [4], is done in such a way that it reflects the null.

Ideally, an analysis of the gambler's fallacy in the context of penalty shootouts would require data where behavior of kickers and goalkeepers is completely independent. However, good kickers are often able to shoot in the direction opposite to the dive direction of the goalkeeper. This fact could be particularly problematic for M&H's analysis, as behavior after a series of consecutive shots in the same direction can only be observed towards the end of the shootout when often the best penalty shooters line up [5]. A potential additional bias, also discussed by M&H, is that kickers have a 'natural side' — that is, left- or right-footed kickers have different probabilities to shoot left or right. Finally, it is not clear whether shots in the center terminate a series or not.

We tested for the gambler's fallacy in extended data, and also in data from a laboratory experiment in which decisions of kickers and goalkeepers are fully independent. We acquired data on penalty shootouts from the sport business company deltatre. The data contain precise information on the dive direction of goalkeepers (left/middle/right) and on the kick direction of penalty-takers (reported as grid coordinates). Overall, we have information on 367 penalties in 38 shootouts, of which 16 are not in M&H's original data. We follow M&H and remove penalties in which either the goalkeeper or the kicker chose center. This leaves us with 319 observations.

Column 2 of Table 1 shows that no significant gambler's fallacy can be observed in our new data set; this finding remains valid if we merge both datasets (see column 3). Also for kickers we find no evidence of a gambler's fallacy (see Table S1 in the Supplemental Information). It is interesting, however, to note that, in contrast to the behavior of kickers, all values in Table 1 for real-world shootouts are above 50% — that is, goalkeepers have a tendency to dive into the opposite direction of the last kick's direction. Analysing data of all dives in the last row of the table shows that goalkeepers do so in about 55% of all dives. Although there is no significant gambler's fallacy, M&H's analysis is valuable as it leads to a simple message for kickers: always shoot in the same direction as the previous kicker of your team did.

In order to get data in an idealised setting with fully independent behavior of kickers and goalkeepers, we ran a computerized laboratory experiment. For each session 12 subjects were invited. We ran five sessions consisting of several rounds where each round simulates one penalty shootout: subjects were randomly assigned to a team (blue or red) and a position (goalkeeper or kicker no. 1–5). For each penalty, goalkeeper and kicker decided simultaneously and independently for one corner (left or right). Their decisions and the outcome of the penalty — goal if both subjects decided for opposite directions, no goal otherwise — were announced on screen to all subjects. If there was a draw after 10 penalties, the round was decided by a coin-flip. At the end of a session, one round was randomly drawn. Members of the team that won this round received 20 Euros each, members of the losing team 10 Euros. Column 4 of Table 1 shows that also in this ideal lab experiment no gambler's fallacy can be observed.

In summary, we argue that the appropriate test for detecting a gambler's fallacy in the data of M&H is a binomial test. Using this test, we do not find statistically significant evidence for a gambler's fallacy in M&H's original data [2]. The same holds if we extend M&H's data and analyze data from an idealized laboratory experiment. Therefore, M&H's conclusions should, in our view, be taken with some caution.

SUPPLEMENTAL INFORMATION

Supplemental information contains details of the experimental design as well as one table which analyzes sequential behavior of kickers and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.05.007.

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[1]Kiel Institute for the World Economy, 24105 Kiel, Germany. [2]Department of Economics, University of Kiel, 24098 Kiel, Germany, and Department of Economics and Econometrics, University of Johannesburg, 2006 Auckland Park, South Africa.
*E-mail: sebastian.braun@ifw-kiel.de (S.B.), ulrich.schmidt@ifw-kiel.de (U.S.)

