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The hot hand phenomenon as a cognitive adaptation to clumped resources

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Abstract

The hot hand phenomenon refers to the expectation of "streaks" in sequences of hits and misses whose probabilities are, in fact, independent (e.g., coin tosses, basketball shots). Here we propose that the hot hand phenomenon reflects an evolved psychological assumption that items in the world come in clumps, and that hot hand, not randomness, is our evolved psychological default. In two experiments, American undergraduates and Shuar hunter–horticulturalists participated in computer tasks in which they predicted hits and misses in foraging for fruits, coin tosses, and several other kinds of resources whose distributions were generated randomly. Subjects in both populations exhibited the hot hand assumption across all the resource types. The only exception was for American students predicting coin tosses where hot hand was reduced. These data suggest that hot hand is our evolved psychological default, which can be reduced (though not eliminated) by experience with genuinely independent random phenomena like coin tosses.

Keywords: Decision-making; Ecological rationality; Patchy environment; Aggregation; Streaks; Hot hand

1. Introduction

1.1. A brief history of the hot hand phenomenon

A large body of research in psychology suggests that people have difficulty thinking about randomness, often perceiving patterns that simply are not there (e.g., Falk & Konold, 1997; Nickerson, 2002). In particular, people seem to have difficulty thinking properly about independent events: series of events each of whose outcome has no influence on the outcomes of future ones. One of the best known of these confusions was first identified by Gilovich, Vallone, and Tversky (1985) and has come to be known as the hot hand fallacy (here, because we will be questioning whether it is a fallacy, we will refer to any assumption of clumps as the "hot hand phenomenon" or, more simply, "hot hand"). The phenomenon was first identified in observers' predictions about the likely outcomes of basketball shots. Gilovich et al. (1985) found that both basketball players and fans judged that a player's chance of hitting a shot was greater following a successful shot than a miss. These judgments revealed an implicit assumption of "streaks" or "runs" in players' shooting success. This can be described as a positive recency effect: a successful shot, or "hit," boosts the observers' subjective probability of another hit. In other words, the hot hand phenomenon reflects an implicit assumption on the part of the observer that hits are positively autocorrelated, or clumped. However, when Gilovich et al. (1985) analyzed the actual data on which subjects' predictions were made, they found that the shots were, in fact, independent. The hot hand assumption was therefore a mistake, at least in this case.

The hot hand phenomenon is not limited to basketball, however. There exist a variety of studies showing that subjects expect and indeed perceive clumps in data that have no clumps. While most of these studies have been done in other sports disciplines (e.g., Clark, 2003; Dorsey-Palmateer & Smith, 2004), the hot hand phenomenon has also been reported in betting markets (Camerer, 1989) and finance (Hendricks, Patel, & Zeckhauser, 1993). Positive recency effects can also be shown in prediction tasks, such as when placing bets in roulette games (Croson & Sundali, 2005).

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However, most previous studies of hot hand have examined relatively artificial and evolutionarily novel environments like sports and betting markets, so the full range of environments where hot hand might occur is not yet known.

1.2. Previous explanations for hot hand

A variety of explanations for the hot hand phenomenon have been proposed. Most of these view hot hand as the by-product of some cognitive mechanism or process which might be "adaptive," or useful, in some cases, but is misapplied in the case of basketball shots, coin tosses, and other sequences of independent events. What varies in these explanations is the cognitive process that causes the hot hand effect.

The original explanation of hot hand by Gilovich et al. (1985) was that subjects bring an assumption of "representativeness" to the data: hot hand reflects "a general misconception of chance according to which even short random sequences are thought to be highly representative of their generating process" (Gilovich et al., 1985, p. 295), so subjects mistakenly infer an autocorrelation that extends beyond the short sequence sampled. Others suggest that hot hand results from overgeneralization of patterns that subjects have learned from experiences of real world distributions where there are streaks, but that do not apply to cases such as free throws and coin tosses. Ayton and Fischer (2004), elaborating on an argument originally offered by Estes (1964), point out that hits are autocorrelated in a variety of domains of human performance such as golf, darts, and horseshoe pitching (Gilden & Wilson, 1995, 1996; Smith, 2003) and suggest that subjects have learned, perhaps mistakenly, to expect clumps in other domains. Similarly, Raab, Gula, and Gigerenzer (under review) show that streaks exist in volleyball, and Miyoshi (2000) in basketball, suggests that hot hand might not be a fallacy at all. There is thus disagreement about whether hot hand is a fallacy even for sports (Bar-Eli, Avugos, & Raab, 2006). Of course, these arguments would not justify a hot hand assumption for cases such as coin tosses, which are genuinely independent.

Burns (2004) has made perhaps the most explicit proposal that hot hand is adaptive. According to his proposal, this could be true in at least two possible ways. First, he suggests and shows via simulation that, if hot hand is used as a basis not for prediction per se but for decision making—deciding to whom to pass the ball— "belief" in hot hand leads to more scoring by the team because small samples of hit rates are predictive of overall scoring ability, and the ball is passed more frequently to players that recently scored. Second, if there really *are* clumps in the world, then assuming there are clumps will lead to good predictions. Our proposal below elaborates on this latter suggestion by explicitly proposing that hot hand is an evolved cognitive adaptation to a world where clumps are the norm rather than the exception and represents a psychological default to expect clumps in a wide variety of domains.

1.3. Hot hand as an evolved cognitive adaptation

We suspected that prior research on hot hand might have started from the wrong place in asking why people are so bad at thinking about random (independent) events and in focusing on relatively novel domains such as sports and betting. From an evolutionary perspective, we expect cognitive skills to be adapted to the kinds of fitness-relevant problems people faced in ancestral environments, not modern contexts like sports, betting markets, or artificial laboratory tasks. The original hot hand results were considered surprising because they showed that people are poor at making predictions about randomness, but we suggest that it might have been more surprising if it had been the other way around. Truly independent and random events are likely to have been relatively rare in ancestral environments, and there would have been little or no selective advantage to trying to make predictions about the ones that were. Instead, most of the objects and events that would have had a fitness impact on human decision-making would have exhibited at least some statistical patterning, and selection would have occurred if people could detect and take advantage of such patterns in their decision making in a fitness-promoting way. It is in this context—taking advantage of statistical patterns in the environment for the purposes of decision-making—that we believe hot hand evolved.

We propose that hot hand is a cognitive adaptation that evolved to help people predict the presence of items in space and time, that it is designed to exploit the fact that those items are clumped in space and time, and that it evolved for the purpose of foraging, broadly construed. We will briefly explain each of these three features of our proposal in turn.

First, consider the psychological context in which hot hand was originally discovered and has since been repeatedly confirmed. Hot hand occurs when subjects experience a sequence of events that can be classified in a binary fashion into hits or misses and try to predict future ones. Not all human decision-making contexts exhibit this feature of sequential search. In ancestral environments, we believe that the most common case in which such sequential search would have occurred would have been foraging, which we will define below.

A second point to consider is that hot hand appears particularly well-suited for items that are clumped (positively autocorrelated) in space and time, as opposed to truly random (zero autocorrelation) or dispersed (negatively autocorrelated). Indeed, hot hand is empirically operationalized as positive autocorrelation in subjects' predictions. We suggest that it is not a coincidence that an implicit assumption of clumps is easily evoked. In nature, clumps are the norm rather than the exception in diverse natural phenomena including the distributions of animals, plants, minerals, water, human settlements, and weather (e.g., Taylor, 1961; Taylor, Woiwod, & Perry, 1978). There is good reason to suspect that some degree of clumpiness was common for most of the natural resources that humans would have encountered over evolutionary time because most causal processes generating resource distributions do not exhibit strict local independence (c.f. Wilke, 2006). For example, animals and plants tend to cluster together because of common habitat and seasonality preferences, predator avoidance, and other factors (Krause & Ruxton, 2002). The existence of one or more decision-making adaptations to exploit such clumps might be expected on evolutionary grounds, and the features of hot hand seem well suited to do so.

Finally, we suggest that the context in which hot hand evolved, its proper domain, was foraging. We mean this very broadly, however, to include not just food—the resource type that is most commonly associated with foraging—but also the full range of objects (fruits, food animals), places (sites to build shelter, water sources), people (mates, social partners), and information that exhibited patterns in space in time, that ancestral humans sought for, and that affected their fitness. In behavioral ecology, a rich body of theory of the decision-making mechanisms involved in foraging has been developed that examines how those mechanisms are shaped by the distribution of resources and information in the environment (Bell, 1991). The idea that resources come in clumps, or patches, is central in this literature, and much of it has focused on how animals should make decisions under uncertainty in environments where resources are clumped (Charnov, 1976; Iwasa, Higashi, & Yamamura, 1981). Studies with a variety of animal species, including humans, have supported the predictions of these models (e.g., Cuthill, Haccou, & Kacelnik, 1994; Fortin, 2003; Hutchinson, Wilke, & Todd, 2008). While foraging theory was originally developed in the context of food search, its formal assumptions are actually about the spatial and temporal distributions of items and their payoffs in any currency, not just calories. It is therefore not necessarily specific to food but can be used to understand and predict decision-making in any context where resources are patterned. Recently, psychologists have realized that models from foraging theory apply well to problems of information search and have developed a theory of information foraging that closely predicts, for example, how subjects search for information on the internet (Pirolli, 2007) or retrieve information from memory (Wilke, Hutchinson, Todd & Czienskowski, in press).

Our suggestion, then, is that hot hand is an adaptation that is tuned less to particular types of items than to how they are structured in the environment; it is ecologically rational in this sense (Haselton et al., submitted; Todd, Gigerenzer, & the ABC Research Group, in press)[1] We view this proposal as fitting into a growing body of work investigating how specific ecological contexts, including foraging, have shaped human cognition and specialized cognitive mechanisms (New, Krasnow, Truxaw, & Gaulin, 2007; Todd et al., in press; Uskul, Kitayama, & Nisbett, 2008).

1.4. Evolutionary logic of the hypotheses

Based on this reasoning, we propose that hot hand is an evolved default assumption that is applied to a wide variety of domains in which items are quantifiable and distributed across the environment in space and time. What we mean by a "default" is that we possess an evolved foraging system that is designed to help us locate and make decisions about clumped resources, but we do *not* possess an evolved system designed to help us think about truly random ones. As part of the clumped resource system, we might expect a default setting of how patchy resources in general are expected to be, when no experience with a particular resource is available (this default could reflect a weighted average of the patchiness of resources commonly encountered by humans over time, or it could have multiple default settings triggerable by environmental cues).

An important part of all known foraging mechanisms is a learning interface, which adjusts important decision-making parameters—such as how patchy a particular resource is—based on experience (Gallistel, 1990). A flexible foraging system that updated its parameters based on learning (using a specialized learning algorithm) would clearly be selectively favored over a nonflexible one. Additionally, a learning system that started with broadly ecologically applicable priors would be selected over one with no defaults at all. We therefore expect subjects to exhibit a default assumption of clumpiness, but we expect the clumpiness parameter to be adjustable for different resources based on experience (how adjustable it is, however, might depend on the category of resource). On this view, subjects with experience of truly independent resource distributions might be able to "learn their way out of," or partially out of, the clumpiness default; understanding randomness would be a learning achievement.

An additional design feature that we might expect, if hot hand represents an adaptation to clumped resources, is that there will be differential effects for hits and misses. In particular, there will be an expectation of clumps for hits (resources), but not necessarily for misses (lack of resources). We expect stronger positive recency following hits than misses because the mechanism is designed to identify streaks of hits that are clustered due to a common underlying causal process, but the absence of hits may not be clustered by an underlying process (e.g., water sources vs. places where there is no water). Gilovich et al. (1985) found such a differential hot hand effect for basketball free throws. This may be related to a "win-stay, lose-switch" (or simply "win-stay") strategy (Nowak & Sigmund, 1993). Foragers might adopt a random search pattern until they find a resource hit and then elevate their expectation of additional resources nearby (Sims et al., 2008).

[1] By this, we do not mean that hot hand is "domain general" but, rather, that its domain is quantifiable resource items encountered in sequential search. We are also not ruling out the possibility of some effects of resource type within this superordinate domain. For example, we conjecture below that hot hand might be stronger for natural resources than for artificial, evolutionarily novel ones.

Finally, based on the kind of evolutionary reasoning laid out above, we expect deployment of the hot hand mechanism to have some boundary conditions. In particular, the ecological context in which clumps are likely to occur is when subjects are sampling the environment by moving through it in space or time. We therefore expect this kind of sequential sampling to be a necessary condition for hot hand. In such sampling conditions, positive autocorrelation occurs because the underlying process that causes a resource to occur in Place P or Time T makes it more likely that a second item will occur nearby in space or time. However, this condition does not necessarily hold when the foraging activity itself is having an effect on the probability of future encounters, as when resources are being removed from a finite pool without replacement. In such circumstances, we do not expect a clumped psychology (hot hand) to be deployed but, rather, a *depletion psychology.* As it happens, there is another cognitive "fallacy" called the "gambler's fallacy" (Tversky & Kahneman, 1971) that we hypothesize is the result of an evolved depletion psychology. The gambler's fallacy is the opposite of hot hand in that it assumes negative autocorrelation, for example, that a streak of heads increases the probability of tails. This makes sense if the underlying psychology assumes a finite pool of heads. We are currently conducting a study of this depletion psychology hypothesis.

To explore the proposal that hot hand is an evolved psychological adaptation to clumped resources, we developed an experimental task that simulated sequential search for resources in a computer game environment and asked subjects to make moment-to-moment predictions about the forthcoming presence or absence of resources as they navigated through the environment. Crucially, all the resource distributions were generated via a randomizing algorithm equivalent to a series of coin tosses, so any "hot handedness" came from the subjects, not the data. We used an array of different resource types to examine how broadly the hot hand assumption is applied and whether it could be attenuated for some resource types as opposed to others. The hypotheses that we tested, developed using the logic above, are as follows:

Hypothesis 1. Hot hand is a default assumption

When subjects are faced with predicting sequences of resources in time or space or both (e.g., encounter along a linear trajectory), they will exhibit a default assumption of clumps (i.e., positive spatiotemporal autocorrelation), as opposed to nonindependence or negative autocorrelation, even in independent random data.

Hypothesis 2. Hot hand is triggered by searching for quantifiable resource items

We expect hot hand to be deployed in cases where subjects are engaged in sequential search for resources, defined as events or objects that can be quantified and that exhibit "hits" or "misses" in space or time, when subjects are moving through a continuous resource space as opposed to sampling from a fixed pool without replacement.

To examine whether hot hand varies by resource, we examined five resource types: fruits on trees in a forest, birds' nests on trees in a forest, bus stops along a city street, parking spaces along a city street, and a sequence of coin tosses. Coin tosses are a paradigm case of independent events, so we thought this would be the best possible case for attenuation or absence of hot hand. The remaining four resources were arranged in a 2×2 design: natural (fruits, nests) versus artificial (bus stops, parking spaces), and clumped (fruits, parking spaces) versus dispersed (nests, bus stops). We thereby sought to examine (a) whether natural resources prompt hot hand more than artificial, evolutionarily novel ones and (b) whether relatively dispersed resources might attenuate hot hand. Our clumped/dispersed logic was as follows: fruits come in patches on trees, and parking spots (i.e., white zones) come in streaks on city streets, interleaved with red zones where parking is not permitted. In contrast, nests are often dispersed rather than clumped due to territoriality, and bus stops are dispersed to maximize coverage of the landscape. In a series of pilot studies, we confirmed that subjects shared these intuitions about relative dispersion of these resources.

Hypothesis 3. Differential effects for hits and misses

We expected stronger hot hand (i.e., stronger positive recency) following hits than misses because the mechanism is designed to identify streaks of hits that are clustered due to a common underlying causal process, but the absence of hits may not be clustered by an underlying process.

Hypothesis 4. Learning away from hot hand

As a default, we expected the hot hand assumption to be the strongest for natural, forageable resources. Patterns of judgment approaching true randomness, however, could be learned in the case of truly independent random phenomena such as coin tosses. We thus expected attenuated or absent hot hand for coin tosses in a population where people are familiar with them (UCLA students) but hot hand for coins when people have little experience of coin tosses as a randomizing device (a South American indigenous population).

2. Materials and methods

We conducted two experimental studies in which participants played a computerized sequential foraging game in which they experienced a sequence of 100 hits and misses and were asked, after each event in the sequence, to predict whether the next event would be a hit or miss (see Supplementary materials for details). Crucially, these event distributions were equivalent to a series of coin tosses, each with a .5 probability of a hit or a miss, and each locally independent (distributions were constrained to have a global proportion of 50 hits : 50 misses). What was manipulated was how these resources were framed: in some cases, they were depicted as actual coin tosses and, in other cases, fruits, bird nests, parking spots, and bus stops. At each step in the game, subjects saw a square in the middle of the screen that showed either a hit or a miss in the form of a picture of the resource (e.g., a tree with a bird nest in it) or absence thereof (e.g., an empty tree). At each step, subjects were asked to predict whether the next step would be a hit (e.g., nest) or a miss (e.g., no nest) by pressing a button, upon which they were shown the next step, one at a time, up to 100. Afterwards subjects answered a free response question about their strategy use.

Experiment 1 was conducted with UCLA undergraduates, using all five resources (coins, fruits, bird nests, parking spots, and bus stops) in a between-subjects design. The 100 participants (50 women, 50 men, mean age 21 years) were randomly assigned into five experimental conditions of 20 people. There was an equal number of women and men in each condition. Participants were paid at the end of the experiment according to their overall foraging success ($0.05 for each correct prediction) and a baseline attendance fee ($2.50). This design enabled us to examine Hypotheses 1–3.

Experiment 2 was a cross-cultural version of the same experiment, comparing UCLA undergraduates with Shuar hunter–horticulturalists from Amazonian Ecuador. Shuar participants were from a rural village of about 150 people where foraging is common. Each participant played the fruit game and the coin game, on different days, counterbalanced order, to compare hot hand for fruits, a clumped natural resource that Shuar regularly forage for but UCLA students do not, with coin tosses, a genuinely nonclumped random item with which UCLA students have familiarity but Shuar adults do not. At UCLA, the sample was 32 adults (16 women, 16 men, mean age 21 years). The Shuar sample was 32 adults (16 women, 16 men, mean age 27 years). Participants in the UCLA sample received $0.05 for each correct prediction and a show-up fee of $2.50 per testing session, and Shuar participants received $0.02 for each correct prediction (we used different pay rates to reflect differences in daily wages). Prior to playing, Shuar participants were asked if they were familiar with coin tosses, and if they were not, they were shown several coin tosses and asked to predict the outcome for each toss. Shuar subjects also completed a post-game questionnaire about their foraging experience and familiarity with randomizing devices. This design allowed a partial replication of our first study (Hypotheses 1–3) and, in addition, a cross-cultural comparison to test Hypothesis 4.

3. Results

3.1. Experiment 1

Based on the content of the 100 binary spaces that make up each environment (i.e., resource hits vs. resource misses) and the choices participants made in our sequential foraging game, we computed a subjective alternation probability, $p(A)$, for each participant:

$$\text{Subjective } p(A) = 1 - \frac{\text{Number of outcomes chosen identical to previous resource spot}}{\text{Number of choices} - 1}$$

This index measures subjects' expectations of "clumpiness": the proportion of cases in which an individual predicted the following space to be the same as the current space (i.e., hit –> hit, miss –> miss). Subjective $p(A)$ varies from 0 (never alternating, i.e., always predicting the same as what was in the last space) to 1 (always alternating from what was in the last space). It thus indicates how much aggregation (values lower than .5), randomness (values around .5), or dispersion (values higher than .5) participants judged in their experimental resource distribution, based on their actual decisions whether the next spot would be a hit or miss (cf. Falk & Konold, 1997).

Hypothesis 1 predicted that subjects would exhibit hot hand [i.e., $p(A)$ less than .5] broadly across the resource types, while Hypothesis 2 predicted that within this general trend there might be variation by resource type. The scores in Table 1 show that the mean subjective $p(A)$ is indeed lower than .5 in all five resource domains, indicating an assumption of clumpiness for all resource types. Across both sexes, the values are lowest for nests (.30) and fruits (.37) but closest to the objective $p(A)$ for coin tosses (.45) and bus stops (.43). We conducted an analysis of variance (ANOVA) with each participants' subjective $p(A)$ value as the dependent variable, domain and sex as between-subject factors, and age as a covariate. The type of domain had a significant effect on subjects' perception of the environmental resource distribution, $F(4,99)=3.85$, $p=.006$, $\eta^2=.147$, but there was no main effect for sex and no interaction between resource type and sex or age (all F's<.41).

Aside from coins, the four resources examined varied in two dimensions: natural (nests, fruits) vs. artificial (parking spaces, bus stops) and clumped (fruits, parking spaces) vs. dispersed (nests, bus stops). We ran a second ANOVA on

Table 1
Mean subjective alternation probability and standard deviations across resource domains (Experiment 1)

	Females		Males	
Domain	Mean	S.D.	Mean	S.D.
Fruits	0.36	0.10	0.37	0.11
Nests	0.27	0.13	0.33	0.20
Coins	0.45	0.17	0.45	0.08
Parking	0.39	0.10	0.35	0.16
Bus stops	0.42	0.07	0.44	0.09

these four resources with natural vs. artificial, clumped vs. dispersed, and sex as between-subjects factors, and age as a covariate. There was a main effect of natural vs. artificial resources [$F(1,99)=5.78$, $p=.019$, $\eta^2=.075$] but no main effect for clumped vs. dispersed [$F(1,79)=0.11$, $p=.918$]. No significant effects occurred for sex or age. However, there was a significant interaction effect between our two domain variables, natural/artificial and clumped/dispersed [$F(1,79)=4.77$, $p=.032$, $\eta^2=.063$] indicating that participants did not perceive these dimensions to be entirely independent. Although both mean subjective $p(A)$ values are lowest for the domains in the natural resource category, the largest difference in means is found when comparing the two resources having the dispersed distributions (i.e., nests and bus stops).

Because the experiment involved 100 guesses with feedback, we could examine whether participants' subjective $p(A)$ changed over the course of the game. To examine this, we divided the 100-guess game into five segments and computed participants' subjective $p(A)$ value for each (i.e., after visiting 20, 40, 60, 80, or all 100 resource spots) and ran a repeated-measures ANOVA with these time bins as an additional within-subject factor. The results were nonsignificant, indicating that subjects were equally hot-hand over time [$F(3.56,316.91)=1.28$, $p=.280$; with Greenhouse–Geisser correction]. If at all, it seems hot hand was slightly stronger towards the end of the experiment (see Fig. 1). In other words, subjects brought an assumption of clumps into the task, and it remained over the course of 100 trials, not attenuating despite the lack of actual clumps in the data.

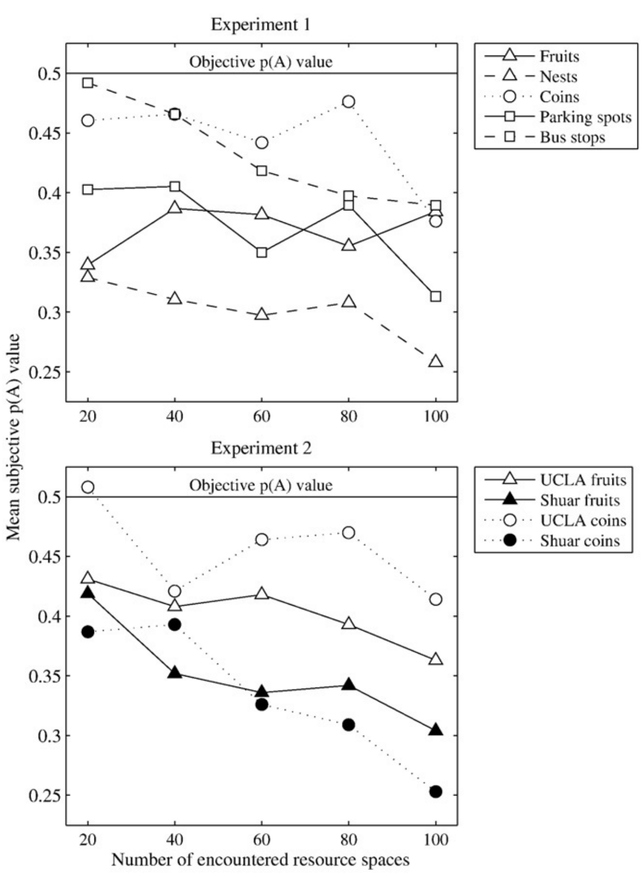

Fig. 1. Mean subjective alternation probability in each quintile of 20 spaces.

Table 2
Qualitative questionnaire data

Domain	Strategy use: Yes	Strategy use: No	Strategy coding: A	Strategy coding: R	Strategy coding: D
Experiment 1					
Fruits	12	6	60%	30%	10%
Coins	15	4	50%	8%	42%
Nests	10	5	42%	29%	29%
Parking	10	9	60%	20%	20%
Bus stops	11	7	57%	29%	14%
Experiment 2: Shuar					
Fruits	23	8	92%	0%	8%
Coins	24	8	87%	0%	13%
Experiment 2: UCLA					
Fruits	14	13	86%	7%	7%
Coins	12	15	46%	31%	23%

Counts show the number of subjects giving feedback on strategy use (left) and the percentage of non-blank strategy reports (right) that were coded mentioning aspects of aggregation (A), randomness (R) or dispersion (D).

These analyses show that participants assumed clumpiness (i.e., autocorrelation) in their predictions when both hits and misses are included. To examine Hypothesis 3—that hot hand would be greater for hits than misses—we calculated separate $p(A)$ values for hits and misses. Across all five conditions, the alternation probability after a hit is significantly lower than the alternation probability after a miss [(0.33 vs. 0.44), $t(99)=-3.52$, $p<.001$]. This result holds for all domains pooled for both sexes [females: $t(49)=-2.97$, $p=.005$; males: $t(49)=-2.09$, $p=.042$], with two specific post hoc tests reaching statistical significance when testing individual domains by sex: females foraging for fruits [(0.28 vs. 0.44), $t(19)=-3.05$, $p=.014$] and nests [(0.19 vs. 0.36), $t(19)=-2.48$, $p=.035$].

After the experiment, subjects were asked to state any strategy they used during the game (free response). After eliminating all written reports that were either left blank or were unclassifiable, the remaining 46 statements were coded based on whether they mentioned aggregation (e.g., "trying to figure out patterns from previous nests to guess the following clumps"), randomness (e.g., "just guessed"), or dispersion (e.g., "I chose the opposite of what came"). Across domains, the mode of these coded responses (42–60%) was aggregation (Table 2).

3.2. Experiment 2

In Experiment 2 as in Experiment 1, mean subjective $p(A)$ values were lower than the objective $p(A)$ of .5, indicating hot hand (see Table 3). This was consistent with Hypothesis 1 which predicted that hot hand would apply broadly across resource types. We conducted an ANOVA

Table 3
Mean subjective alternation probability and standard deviations across cross-cultural samples and resource domains (Experiment 2)

	Shuar				UCLA			
	Females		Males		Females		Males	
Domain	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Fruits	0.32	0.14	0.38	0.15	0.39	0.14	0.41	0.12
Coins	0.28	0.10	0.38	0.11	0.44	0.10	0.46	0.11

with participants' subjective $p(A)$ value as the dependent variable; population (Shuar participants or UCLA students), sex, order of testing (fruits first or coins first), and resource domain nested within subject as between-subject factors; and age and the number of days between testing sessions as a covariate. Population had a main effect on $p(A)$, $F(1,63)=4.35$, $p=.041$, $\eta^2=.069$, such that Shuar participants had significantly lower $p(A)$ values compared to UCLA undergraduates. There were no main or interaction effects for domain, sex, order, number of days, or age across both samples (all F's<.91).

Perceptions of the resource distributions in the UCLA sample were comparable to those of Experiment 1 with the domain of fruits (0.40) perceived as more aggregated than that of coins (0.45). Both domain means were (marginally) significantly different in their subjective $p(A)$ values [$t(31)=-2.02$, $p=.052$], but there were no differences between the conditional $p(A)$ values for hits and misses in either fruits [$t(31)=-1.79$, $p=.097$] or coins [$t(31)=-0.25$, $p=.801$]. The Shuar, however, had a very different perception about the two resource domains: They treated both fruits and coins as equally clumped [0.35 vs. 0.33, $t(31)=0.82$, $p=.415$]. Separate post hoc tests for each domain and sex revealed significant differences in the conditional $p(A)$ values for hits and misses for Shuar females foraging for fruits [0.29 vs. 0.36, $t(15)=-3.40$, $p=.004$] and Shuar males predicting coin flips [0.35 vs. 0.42, $t(15)=-2.75$, $p=.015$].

We ran a repeated-measures ANOVA with time bins and resource domain as additional within-subject factors to check for experience effects throughout the study. However, consistent with prior results, there was no significant change over time in participants' subjective $p(A)$ values [$F(1.98, 210.84)=1.81$, $p=.148$; with Greenhouse–Geisser correction]. The lower part of Fig. 1 visualizes this.

On the postgame questionnaire (Table 2), about three fourths of the Shuar participants reported having used a strategy, whereas only half of the UCLA students did so. The majority of responses in both samples reflected a clumped strategy (hot hand) but much more so with the Shuar reports. Unlike some of the UCLA responses, no Shuar strategy report mentioned any aspects of randomness.

For Shuar participants we conducted an additional postgame interview assessing frequency of various foraging activities (hunting, fishing, gathering, gardening, and walking in the woods), as well as familiarity with betting on games and coins as a randomization device. Overall, there was only one significant relationship between interview responses and subjective $p(A)$ values: Women high in experience with gardening work tend to have subjective $p(A)$ values that are more towards dispersion [$r_s(16)=.55$, $p=.030$]. This could possibly reflect the fact that plants planted in gardens tend to be dispersed, as they are planted by hand to be somewhat evenly spaced.

4. Discussion

Overall, the results of both experiments support our proposal that hot hand is a default assumption that is widely applied across resource types (Hypothesis 1). This was true in two disparate populations, UCLA undergraduates and Shuar hunter-horticulturalists, so it is not likely to be a byproduct of some aspect of Western industrialized culture. We conjectured that hot hand would be triggered by any sequential search for resources that come in quantifiable hits and misses (Hypothesis 2), and the data support this: only for coin tosses and bus stops, and only in the UCLA population (where there is familiarity with these resources) did subjective $p(A)$ approach .5.[2] Though hot hand was slightly stronger for natural than artificial resources, as might be expected in a mechanism evolved for natural environments, we were unable to manipulate hot hand by varying the degree to which resources are intuitively clumped or dispersed. In Experiment 2, the fact that hot hand was attenuated in the case of coins and only for UCLA students who are familiar with them as a randomizing device supports our proposal that hot hand is a psychological default that can be learned out of in certain narrow domains of true randomness (Hypothesis 4). Finally, Hypothesis 3, that hot hand would be stronger for hits than misses, received partial support, with a significant result in Experiment 1 and for Shuar participants in Experiment 2 (though the effect was in the predicted direction for UCLA participants).

Taken together, these results suggest that hot hand is not a learned heuristic that is extrapolated from a narrow domain of learning, such as sports, and applied more broadly. Instead, the presence of hot hand across diverse domain types and in two very different cultures supports the idea that hot hand is an evolved default which, in cases of true randomness, must be learned out of rather than

[2] Note that bus stops are actually dispersed in the environment, and our pretesting indicated that UCLA subjects are aware of this. This might explain why subjective $p(A)$ for bus stops got as close to .5 as any other resource besides coins. However, it is interesting to note that subjective $p(A)$ was still on the clumpy side of .5. It is also interesting to note that subjects' subjective $p(A)$ was not equivalently shifted for bird nests, for which pretesting also indicated subjects considered dispersed, perhaps because learning out of the clumped default is easier for artificial resources than natural ones or because UCLA subjects have more real-world experience with bus stop distributions, or both.

learned into. This is further supported by the fact that Shuar adults, who have relatively little experience with or knowledge of coin tosses, exhibited hot hand for coins at approximately the same level for fruits, a natural resource. Hot hand was also present for UCLA students for both natural and artificial resources and was only substantially attenuated in the case of coins and bus stops—suggesting that the students had learned to expect relative nonindependence in these evolutionarily novel items but had still not entirely rid themselves of the hot hand assumption.

Hypothesis 3 proposed an additional possible design feature that might be expected if hot hand is an adaptation to exploit clumps of hits, but not misses: stronger hot hand for hits than for misses. This is what we found in Experiment 1 and the Shuar sample of Experiment 2. This suggests that hot hand does not have to do simply with detecting autocorrelations in any kind of series but, rather, in series of events that are interpreted as hits—encountered resources—in the framework we outlined above.

While the studies presented here found hot hand in a broader range of domains than had been explored in previous research, much remains to be done to explore the boundaries of the phenomenon. These might include a broader range of resource types, a broader range of tasks, and perhaps training studies to examine how and when hot hand can be attenuated. Our initial results, however, suggest that hot hand is a pervasive feature of human thinking. Efforts to look for an intuitive understanding of randomness and even to train people to produce or detect random number sequences have shown that people are poor at understanding randomness, no matter how measured (see Nickerson, 2002). On our view, this is not surprising because it is hard to see what the fitness benefits of understanding true randomness would have been, much less, what kinds of adaptations could have resulted. If the evolutionary model we have proposed here is right, then hot hand is not simply a systematic irrationality or glitch in the system but exists because of the benefits of detecting patterns in a world where such patterns frequently exist.

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Appendix. Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.evolhumbehav.2008.11.004.

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