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Geographic Profiling: The Fast, Frugal, and Accurate Way

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SUMMARY

The current article addresses the ongoing debate about whether individuals can perform as well as actuarial techniques when confronted with real world, consequential decisions. A single experiment tested the ability of participants ($N = 215$) and an actuarial technique to accurately predict the residential locations of serial offenders based on information about where their crimes were committed. Results indicated that participants introduced to a 'Circle' or 'Decay' heuristic showed a significant improvement in the accuracy of predictions, and that their post-training performance did not differ significantly from the predictions of one leading actuarial technique. Further analysis of individual performances indicated that approximately 50% of participants used appropriate heuristics that typically led to accurate predictions even before they received training, while nearly 75% improved their predictive accuracy once introduced to either of the two heuristics. Several possible explanations for participants' accurate performances are discussed and the practical implications for police investigations are highlighted. Copyright © 2004 John Wiley & Sons, Ltd.

A more efficient use of resources and an increase in offender apprehension are the rewards for the police decision-maker who is able to predict accurately the location of an offender's residence from information about where his or her crimes were committed. Although most researchers accept that individuals can address such prediction tasks by using cognitive heuristics, many view heuristic-led judgements as vulnerable to cognitive errors and significantly less accurate than predictions obtained through actuarial techniques (Arkes & Hammond, 1986; Kahneman & Tversky, 1973). However, several recent findings have questioned this assumption, suggesting instead that individuals use fast and frugal heuristics that yield predictions that are as accurate as actuarial techniques (Gigerenzer, Todd, & the ABC Research Group, 1999; Snook, Canter, & Bennell, 2002). The current paper reports a replication of an earlier comparison of human and actuarial performance on a real-world 'geographic profiling' task (Snook et al., 2002), and extends the previous work by examining both individual differences in the availability of appropriate heuristics and the possibilities of reaching effective performance through explicit heuristic training.

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THE ACTUARIAL APPROACH TO GEOGRAPHIC PROFILING

Although actuarial techniques are not likely to guarantee perfect decisions, it is often argued that they will yield better decisions on average than human judges (Hogarth, 1987; Meehl & Rosen, 1955; Swets, Dawes, & Monahan, 2000). In contrast to human decision-makers, actuarial techniques are able to avoid the problems associated with prior expectations, overconfidence, information retrieval, and information processing (Jacob, Gaultney, & Salvendy, 1986; Kahneman, Slovic, & Tversky, 1982; Kleinmuntz, 1990). The demonstration of human judgemental deficiencies has been seen by many as justification for the development of actuarial techniques (Edwards, 1972; Hastie & Dawes, 200l; Meehl, 1954). Such techniques have now been developed and implemented in a variety of contexts, which range from diagnosing and treating infectious diseases (Shortliffe, 1976) to developing win-win agreements in conflict resolution (Sainfort, Gustafson, Bosworth, & Hawkins, 1990).

One quickly developing area of application for actuarial techniques is police investigations, where the outcome of predictions can often have significant consequences for both public safety and human rights (Adhami & Browne, 1996; Rossmo, 2000; Taylor, Bennell, & Snook, 2002). The problem of predicting an offender's home location from crime scene information has received particular attention, with actuarial systems being developed and implemented in both Europe and North America (Rossmo, 2000; Shapiro, 2000). In its most basic form, this geographic profiling task involves using knowledge about the relative locations of an offender's crime sites to predict the highest probable location of his or her residence. By far the most common approach to this task uses mathematical functions to produce a probability surface that shows the likelihood of an offender residing at various locations around the area where their crimes were committed (Canter, Coffey, Missen, & Huntley, 2000; Rossmo, 1993; Taylor et al., 2002). Based on decades of offender spatial behaviour research (Brantingham & Brantingham, 1981; Rengert, Piquero, & Jones, 1999; Turner, 1969), the mathematical functions are typically computed from large data sets to reflect the distribution of distances between offender home and crime locations. Research has demonstrated the accuracy of these geographic profiling systems, with serial offenders' residences typically falling in the top 10% of the prioritized area (Canter et al., 2000; Rossmo, 1993).

AN ALTERNATIVE APPROACH TO ACTUARIAL PREDICTIONS

Recent work has questioned the assumption that actuarial techniques always outperform human judges (Gigerenzer et al., 1999). Studies exploring a number of different prediction tasks have shown that the heuristics, or cognitive shortcuts, used by individuals to reduce complex problems into simpler judgemental ones can perform as accurately as actuarial techniques (Gigerenzer, 2000). This occurs when the heuristic is ecologically rational, that is, when it matches the structure of the environment such that it exploits the general patterns and tendencies in behaviour (Martignon & Hoffrage, 1999; Simon, 1956). The structure of the environment refers to '. . . information that a person, animal or institution knows about a physical or social environment' (Gigerenzer & Selton, 2001, p.187). According to recent work, then, individuals would be expected to have heuristics available to make predictions on the geographic profiling task, where some of these heuristics will be ecologically rational and yield performances that are as accurate as predictions from an actuarial technique.

Although heuristics are thought to be broad and relevant to many prediction tasks, there are likely to be individual differences in terms of heuristic availability (Shiloh, Salton, & Sharabi, 2002). A wealth of research has associated individual differences in the availability of particular heuristics to factors such as gender (Epstein, Pacini, Denes-Raj, & Heier, 1996) and personality traits (Shiloh et al., 2002). In relation to geographic decision-making, Hirtle and Gärling (1992) have shown significant variability in the accuracy and heuristics used by individuals in completing the travelling salesman problem, where participants are asked to identify the shortest distance that links together a series of points. As the complexity of the task increased, some participants demonstrated an ability to draw on alternative heuristics, which typically generated more accurate decisions than those made by individuals who retained their earlier strategy. Since participants' use of the heuristics was not dependent on training, such findings suggest that some individuals may have heuristics available that allow them to be ecologically rational in the geographic profiling task, whereas others will not.

Although differences in the availability of heuristics may develop as a result of a variety of factors, one widely accepted correlate is experience with similar situations (Means, Salas, Crandall, & Jacobs, 1993; Shanteau, Grier, Johnson, & Berner, 1991). This connection is important because it highlights the possibility that individuals can, at least to some extent, learn heuristics (Kahneman & Tversky, 1973). This implication has stimulated research focused not so much on how experience allows individuals to develop heuristics, but on whether the heuristics themselves can be explicitly taught. Much of the work pursuing this question has focused on the possibility of using teaching to reduce biases, such as the fundamental attribution error. For example, Nisbett, Krantz, Jepson, and Fong (1982) argue that providing individuals with a set of inferential rules backed by a scientific understanding can reduce bias, while others have shown that introducing explicit counter-rules may limit the impact of misinformation on judgements (Wyer & Budesheim, 1987). Although such evidence suggests that training can alter the reliance upon inappropriate heuristics, it does not make clear whether explicitly teaching heuristics can lead to their adoption in decision-making. In support of this possibility, Schoenfeld (1979) showed that explicitly introducing participants to problem-solving heuristics had a significant impact on both the speed and accuracy of judgements. These findings are important because they suggest that individuals may be able to adopt and apply an ecologically rational heuristic following simple training (Kleinmuntz, 1990).

Although the research on heuristics indicates that they may offer a powerful solution to real-world prediction tasks, the applicability of heuristics to complex and consequential decision tasks, such as geographic profiling, has received little attention (Shanteau & Thomas, 2000; Sternberg, 2000). In an effort to address this lack of research, Snook et al. (2002) compared the performance of participants and an actuarial technique on a geographic profiling task that required predictions of offenders' home locations based on the distribution of five crime locations. Participants were introduced to a 'Decay' heuristic, which states that many offenders live near their crime locations, and a 'Circle' heuristic, which states that many violent serial offenders live within a circle with the diameter defined by the distance between the offender's two furthermost crime locations. The Decay heuristic is based on the long-established finding that offenders do not travel far from their home to offend (for an extensive review, see Rossmo, 2000) and that the frequency of offending decreases with increased distance from an offender's home location; a concept known as 'distance-decay' (Capone & Nichols, 1975; Turner, 1969). The Circle heuristic originated from evidence showing that the majority of violent serial offenders' homes are located within an area demarcated by their two most distant crimes; a concept known as the 'circle hypothesis' (e.g. Canter & Larkin, 1993; Kocsis & Irwin, 1997; Tamura & Suzuki, 1997). These two heuristics were taught because they mirror those rules that are fundamental to existing actuarial techniques (Canter et al., 2000; Rossmo, 2000). By comparing the accuracy of predictions before and after being provided with these heuristics, Snook et al. demonstrated that groups of participants were able to use these heuristics to improve the accuracy of their predictions. More importantly, the average predictions of participants using these heuristics were found to be as accurate as one popular actuarial technique.

THE CURRENT STUDY

The previous study by Snook et al. (2002) raises the possibility that, in their enthusiasm to develop geographic profiling systems, some researchers have neglected to test the basic question of whether decision-makers can perform accurately given ecologically rational heuristics (Canter et al., 2000; Rossmo, 2000). However, as Snook et al. acknowledge, their study involved only a small number of participants and should be viewed as pilot work whose findings suggest the need for replication and expansion. One area for development is to explore the different types of heuristics that participants' use to make predictions and the accuracy produced by those heuristics. Snook et al. did not attempt to determine whether participants inherently used appropriate heuristics (i.e. before training) to complete the task and so were unable to test for individual differences in their strategies. Moreover, the original study design presented the Decay and Circle heuristics simultaneously, leaving open questions of whether these heuristics have independent effects on predictive accuracy and, more importantly, whether the improvement in performance following training was actually the result of the Decay or Circle heuristic being implemented. Thus, the original study was unable to argue conclusively that teaching heuristics led to participants adopting strategies that improved predictive accuracy.

Given the importance of these questions for understanding the limits and characteristics of heuristics, the current paper replicates and extends the Snook et al. study. The current experiment tests four hypotheses concerning the ability of participants and an actuarial technique to predict the likely residences of serial offenders based on their crime scene locations. Figure 1 is a schematic overview of the experiment, in which the boxes depict the stages of the experiment and the arrows running between the boxes indicate the order in which the stages were presented. Annotations H_1 through to H_4 indicate the stages of the procedure relevant for testing the following four hypotheses:

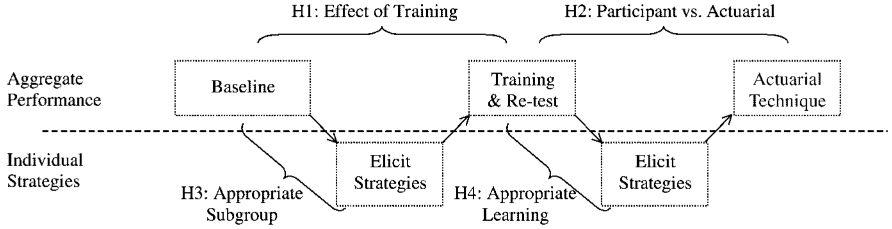

Figure 1. Schematic overview of the experiment

H_1: Participants will improve the accuracy of their predictions when provided with ecologically rational heuristics.

H_2: Participants introduced to an ecologically rational heuristic will make predictions that are as accurate as an actuarial technique.

H_3: Some individuals will use ecologically rational heuristics to make predictions prior to training and these predictions will be more accurate than those who do not use ecologically rational heuristics.

H_4: Participants who initially do not use ecologically rational heuristics will adopt those that are provided during training.

Stages in the top half of Figure 1 combine to allow aggregate performance to be compared before and after training (H_1) and post-training performance to be compared to predictions made by an actuarial technique (H_2). Stages in the bottom half of Figure 1 focus on individual differences in performance and examine the type of heuristics used to complete the prediction task before (H_3) and after training (H_4).

METHOD

Participants

Participants were 215 prospective undergraduate participants and their accompanying guardians attending a recruitment day at The University of Liverpool, UK. Participants were randomly assigned to a Control ($N = 73$), Circle ($N = 68$) or Decay ($N = 74$) group, where the difference in N across the three groups resulted from true random assignment. Of the 199 participants who responded when asked their age, there was no significant difference between the Control ($M = 26$, range 17–57), Circle ($M = 23$, range 17–50) and Decay ($M = 27$, range 17–58) groups (F (2, 199) = 1.37, *ns*). Of the 204 participants who responded when asked their sex, there was no significant difference across the groups in the frequency of females (Control = 54, Circle = 52, Decay = 55) and males (Control = 16, Circle = 12, Decay = 15) groups (both $X^2 < 1$, *ns*). None of the participants reported ever having police employment, previous experience with geographic profiling, or experience investigating interpersonal crimes.

Materials

A set of 10 maps, each depicting the first three murder locations of a different offence series, were randomly generated from a larger database of geographic information for solved serial murder cases in Germany (for more details of the database see Harbort & Mokros, 2001). The maps were scaled from actual maps to fit onto a sheet of A4 paper (map size = 235 mm × 163 mm). The maps were presented in black and white and without topographical features in order to remain consistent with the information used by current actuarial techniques. The maps were integrated into an experimental booklet that contained, in order, on separate pages: (a) a blank cover sheet, (b) instructions to indicate (by marking an 'X') on each of the 10 maps a place where they thought the offender's home was most likely to be located, (c) the 10 maps, (d) instructions to record the strategies they used to reach their decisions, (e) instructions to place the completed maps out of their reach, (f) heuristic training material, (g) the same 10 maps, and (h) instructions to record the strategies they used to reach their decisions. Blank sheets of paper were interleaved between each of the sections of the booklet to ensure that participants could not see the upcoming pages.

The heuristic training section of the booklet (section f) differed according to participants' group assignment. Participants in the Control group were not given any heuristic. Participants in the Decay group received written instructions describing the Decay heuristic, which read, 'The majority of offenders commit offences close to home.' Participants in the Circle group were given written instructions on the Circle heuristic, which read, 'The majority of offenders' homes can be located within a circle with its diameter defined by the distance between the offender's two furthermost crimes.'

Procedure

The three groups of participants completed all phases of the experiment in a single session while seated within a large lecture theatre. Participants were informed that they would be making predictions about the likely home location of 10 serial murderers and that the experiment was not concerned with memory performance. Each participant was asked to work individually through the booklet at his or her own pace and specifically told to refrain from turning over pages until the booklet instructed them to do so. Two experimenters remained in the theatre throughout the experiment to answer any questions and to ensure that the task was completed individually. Completion of all tasks in the booklet took approximately 20 min, after which participants were debriefed through a 15-min presentation on geographic profiling.

Attaining actuarial predictions

Actuarial predictions for each of the 10 presented maps were derived using a negative exponential function (Canter et al., 2000). This function assumes that the probability of locating an offender's residence decreases with increasing distance from an offence, and takes the general form:

$$\mathrm{f}(\mathrm{d_{ij}}) = a^{*}e^{-c^{*}\mathrm{d_{ij}}}$$

where $\mathrm{f}(\mathrm{d_{ij}})$ is the likelihood that an offender's residence will be located at a particular location, $\mathrm{d_{ij}}$ is the distance from the centre of the grid cell (i) to an offence (j), a is an arbitrary coefficient used to provide an indication of the likelihood of finding a home, e is the base of the natural logarithm, and c is an exponent that determines the gradient of the function (Levine & Associates, 2000; Taylor et al., 2002). In the current study, the constant a and exponent c were given values of 1, since this is consistent with the base algorithm implemented in a popular actuarial technique (Canter et al., 2000).

Predictions from the negative exponential function were obtained by inputting x and y coordinates of each crime location into *CrimeStat* (Levine & Associates, 2000). *CrimeStat* is a spatial statistics program for the analysis of crime incident locations. Based on the exact measurement sizes of the standardized maps provided to participants, the total area under consideration in *CrimeStat* was 235 mm $\times$ 163 mm. Therefore, each of the 7000 cells that made up the superimposed grid was 2.35 mm $\times$ 2.33 mm in size. The negative exponential function was then applied around each of the crime locations in order to assign a probability value to each of the grid cells. The probability scores assigned to each grid cell were then summed to produce an overall probability value for each grid cell. The resulting output provides the x and y coordinates of the cell with the highest probability, which was chosen as the predicted home location for the actuarial technique and used in all further analyses.

Measuring predictive accuracy

For both the participant and the actuarial technique, the predictive accuracy was measured in millimetres as the straight-line distance between the predicted and actual home location (henceforth referred to as the 'error distance'). A larger error distance indicates a less accurate prediction of the offenders' residence.

Analysing written responses

The strategies participants used to make their predictions were content analysed by the first author. Categories were derived through a typical grounded approach to categorizing written text, which entailed an iterative refinement and modification of the content dictionary until it clearly reflected the content of descriptions across all participants' data (Glaser & Strauss, 1967; Holsti, 1969; Krippendorff, 1980). The coding scheme was applied by the first author to the responses of each participant, both after the baseline (section d) and after the re-test (section h). Reliability of the coding was assessed by having the second author independently code each response provided by participants after the baseline and having the third author code the responses provided after the re-test. The reliability of coding, measured using Cohen's Kappa (Cohen, 1960), was 0.89 in relation to the heuristics used in the baseline and 0.90 in relation to the heuristics used in the re-test. Both values suggest a high level of agreement between the coders (Fleiss, 1981). Disagreements between the coders were resolved through discussion and mutual agreement prior to analysis.

RESULTS

Hypothesis 1: The effect of teaching ecologically rational heuristics

Figure 2 shows the mean error distances of predictions made across all 10 maps as a function of training. A 2 (pre test $\times$ post test) by 3 (Control $\times$ Circle $\times$ Decay) by 10 (across maps) analysis of variance was computed on participants' error distances with training submitted as a within-subjects variable. The within-subjects comparisons showed a significant main effect of training, $F(1,\ 2108) = 131.13$, $p < 0.05$, $\eta^2 = 0.05$, and a significant two-way interaction of training with group, $F(2,\ 2108) = 22.26$, $p < 0.05$, $\eta^2 = 0.02$. These were subsumed by a significant three-way interaction, $F(18,\ 2108) = 6.30$, $p < 0.05$, $\eta^2 = 0.05$.

Simple main effects were calculated across training for each of the three groups to examine the effectiveness of teaching the heuristics on aggregate performance. There was no significant difference in mean error distance observed for the Control group across baseline (67.3 mm, $SD = 19.0$ mm) and re-test (65.8 mm, $SD = 19.9$ mm), $F(1, 72) = 2.10$, *ns*. This contrasts with the Circle group, whose performance showed a significant decrease in mean error distance from baseline ($M = 69.3$ mm, $SD = 22.3$ mm) to re-test ($M = 59.0$ mm, $SD = 13.3$ mm), $F(1,\ 67) = 21.90$, $p < 0.05$, $\eta^2 = 0.25$. Similarly, for the Decay group, there was a significant decrease in mean error distance from the baseline

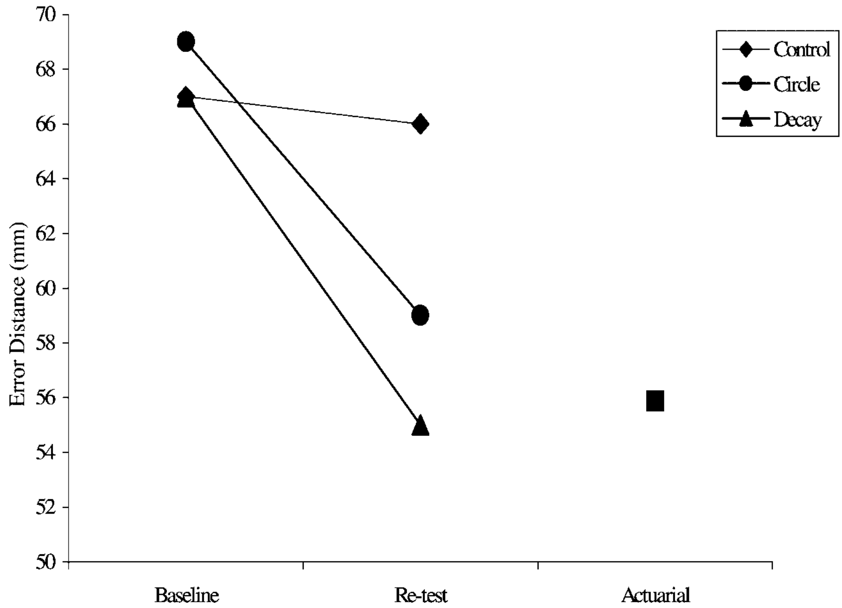

Figure 2. The mean error distances for predictions made in the baseline and the re-test for the three groups and the actuarial technique

($M = 67.3$ mm, $SD = 19.9$ mm) to re-test ($M = 55.4$ mm, $SD = 6.6$ mm), $F(1, 73) = 26.70$, $p < 0.05$, $\eta^2 = 0.27$.

The between-subject comparisons showed a significant difference in performance across the maps, $F(9, 2108) = 199.86$, $p < 0.05$, $\eta^2 = 0.45$. In order to explore the variations in performance among the maps, participants' performance on each map was examined separately. Table 1 contains the results of repeated-measure *t*-tests calculated on the mean group accuracy of predictions across baseline and re-test for each map. A Bonferroni correction was implemented to control the Type-I error rate associated with conducting 10 tests on the data from each group ($\alpha = 0.005$). We adopted a correction for 10 tests because the comparisons intended for each group are independent of the comparisons intended for the other groups, both in terms of involving different participants and different data. The symbol '+' in Table 1 indicates a significant improvement in accuracy from the baseline to the re-test, '−' indicates a significant decrease in accuracy,

Table 1. Test of change in accuracy from the baseline to the re-test for each of the groups across the 10 maps

Group	Map									
	1	2	3	4	5	6	7	8	9	10
Control	±	±	±	±	±	±	±	±	±	±
Circle	+	+	±	±	+	+	+	±	+	+
Decay	+	+	+	+	+	+	+	±	+	−

+ Significant improvement in accuracy from the baseline to the re-test; − significant decrease in accuracy from the baseline to the re-test; ± no significant change from the baseline to the re-test.

and ‘ ± ’ indicates that there was no significant change. As can be seen in Table 1, the Control group showed no significant change in predictive accuracy from the baseline to the re-test for any of the maps. In contrast, the Circle group showed significant improvement in accuracy for seven of the 10 maps, while the Decay group showed a significant improvement in accuracy for eight of the 10 maps.

Hypothesis 2: Comparison between cognitive heuristics and an actuarial technique

Figure 2 also shows the mean error distance for the negative exponential function ($M = 55.9$ mm) across the 10 maps. Since the mean predictive accuracy of the negative exponential function is a constant value, one-sample t-tests were used to compare the performance of the function against participants’ performances following training. Specifically, the mean error distance of the negative exponential function (i.e., 55.9 mm) was used as the test-value and this was separately compared against post-training mean error distances for the Control, Circle, and Decay group. As predicted, the Control group’s performance at re-test was significantly worse than the mean predictive accuracy for the negative exponential function ($t = 4.24$, $df = 72$, $p < 0.05$). However, there were no statistically significant differences between the predictive accuracy achieved by participants in both the Circle ($t = 1.92$, $df = 67$, *ns*) and Decay ($t = -0.67$, $df = 73$, *ns*) groups at re-test and the mean predictive accuracy for the negative exponential function.

As in the previous analysis, the mean error distance for each map was examined separately to determine whether these findings were dependent on the differences among maps. For each map, a one-sample t-test was conducted to determine if the known predictive accuracy of the actuarial technique was significantly better than the mean of re-test performance scores for the Control, Circle and Decay groups (see Table 2). Since each of these comparisons will draw on the actuarial data, this approach requires 30 tests to be computed on related aspects of the data. Consequently, a Bonferroni correction was implemented to limit the potential Type-I errors associated with conducting 30 tests ($\alpha = 0.0016$). The ‘ + ’ symbol in Table 2 indicates that the heuristic was significantly more accurate than the actuarial technique, the ‘−’ indicates that the heuristic was significantly less accurate than the actuarial technique, and the ‘ ± ’ indicates no significant difference in accuracy between the heuristic and actuarial technique. As can be seen in Table 2, predictions of the Control group were significantly more accurate than the actuarial technique for one map, significantly worse for seven maps, but not significantly different from the actuarial technique for the other two maps. In contrast,

Table 2. Test between the Control, Circle and Decay group accuracy in re-test and the actuarial technique in relation to each map

Group	Map									
	1	2	3	4	5	6	7	8	9	10
Control	−	−	−	−	−	±	−	−	±	+
Circle	±	−	−	−	−	±	±	−	±	+
Decay	±	−	±	−	−	±	±	+	+	+

+ Heuristic significantly more accurate than the actuarial technique; − heuristic significantly less accurate than the actuarial technique; ± no significant difference in accuracy.

the predictions of the Circle group were significantly more accurate than the actuarial technique for one map, significantly worse for five maps, but not significantly different from the actuarial technique for the other four maps. Predictions of the Decay group were significantly more accurate than the actuarial technique for three maps, significantly worse for three maps, but not significantly different from the actuarial technique for the other four maps.

Hypothesis 3: Do participants implicitly use ecologically rational heuristics?

The content analysis identified a comprehensive set of 12 strategies that were used by participants before training, five of which were combinations of six core heuristics. Combination categories were retained to ensure that participants' responses could be assigned to a single category, thereby eliminating the double-counting that would occur if participants were allowed to be assigned to multiple categories. Table 3 shows each of the 12 strategies together with a coding definition and their percentage of occurrence in the baseline. As can be seen from Table 3, a total of 49% of participants reported using either the Equidistant heuristic (36.3%), Cluster heuristic (4.2%), or a combination of Equidistant and Cluster heuristics (i.e. Combo 1, 8.4%) prior to instruction.

The three graphs on the left hand-side of Figure 3 represents participants' mean error distances as numbers on a stacked bar graph for each of the experimental groups. The numbers denote the heuristic reported by the participant before training, as coded using the heuristics listed in Table 3. For instance, the number '7' represents a participant who reported making predictions based on the heuristic that the offender should live far away from his crimes (i.e. Commuter). Since the graphs on the left side of Figure 3 show participants' performance at baseline they can be used to determine whether relatively accurate participants also report using a different type of heuristic.

Table 3. Descriptions of the strategies used to make geographic predictions reported by participants in the baseline (percentage of occurrence is in brackets)

Heuristic	Definition
1. Guess (26%)	No strategy indicated or a guess was made
2. Equidistant (36.3%)	Prediction that the offender's residence should be located in the centre of the crimes locations or equidistant from crime locations
3. Cluster (4.2%)	Prediction that the offender's residence should be located near two crimes clustered together
4. Combo 1 (8.4%)	Equidistant and Cluster heuristic
5. Outlier (1.9%)	Prediction that the offender's residence should be located near an outlier crime location
6. Proximity (10.7%)	Prediction that the offender's residence should be located 'near' the crimes
7. Commuter (4.7%)	Prediction that the offender's residence should be located 'away' from the crimes
8. Combo 2 (0.5%)	Equidistant, Commuter and Proximity heuristic
9. Combo 3 (2.8%)	Equidistant and Commuter heuristic
10. Combo 4 (1.9%)	Proximity and Commuter heuristic
11. Combo 5 (0.9%)	Cluster and Commuter heuristic
12. Combo 6 (1.9%)	Equidistant and Proximity heuristic

As can be seen from the three left hand graphs in Figure 3, participants reporting the use of the Equidistant, Cluster, or Combo 1 (i.e. Equidistant and Cluster) heuristics tended to have smaller error distances than those using alternative strategies. Specifically, 35% of participants who reported using the Equidistant heuristic, 33% of participants who reported using the Cluster heuristic, and 33% of participants who reported using Combo 1, fell in the lowest quartile of all error distances. In contrast, participants using heuristics that previous research has shown to be ineffective performed particularly poorly (Canter et al., 2000; Rossmo, 2000). For instance, eight of the 10 participants using the Commuter heuristic typically made predictions that were in excess of 100 mm from the offenders' actual home location (falling in the largest 7% of all error distances).

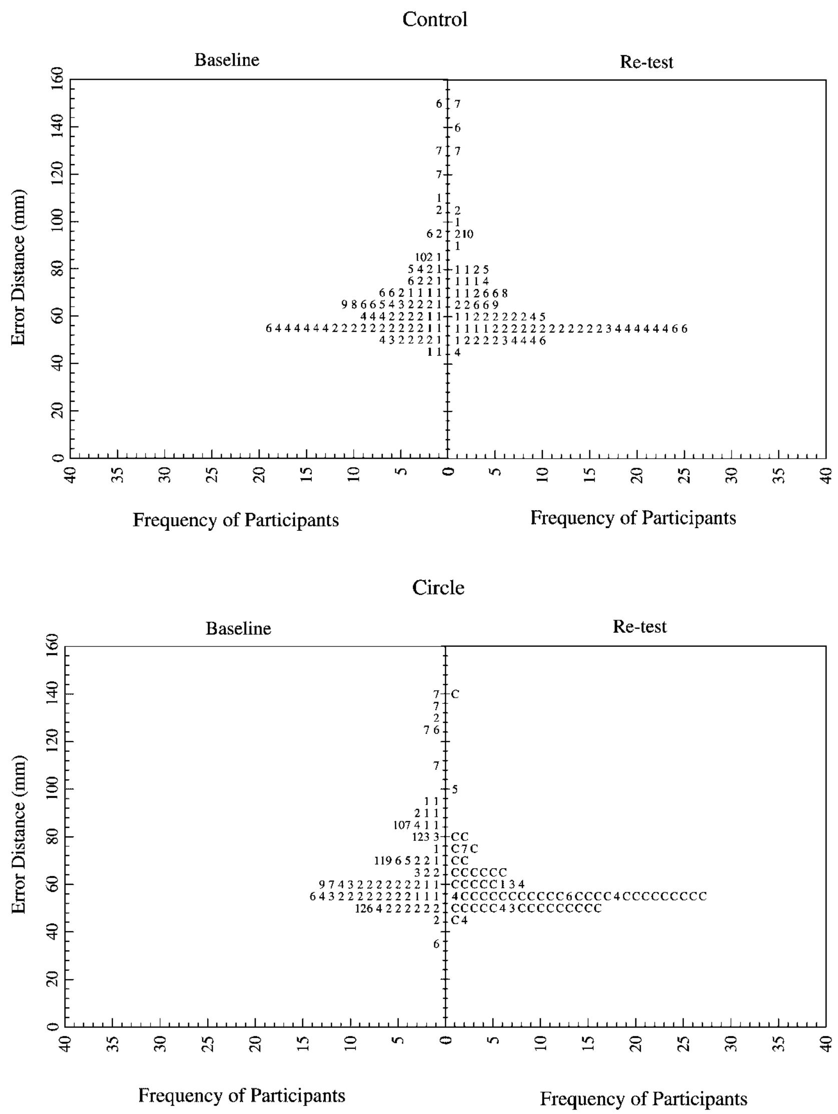

Figure 3. Average error distance for each participant in the baseline and the re-test for each of the three groups. The numbers on the graphs represent the heuristic used by the participant

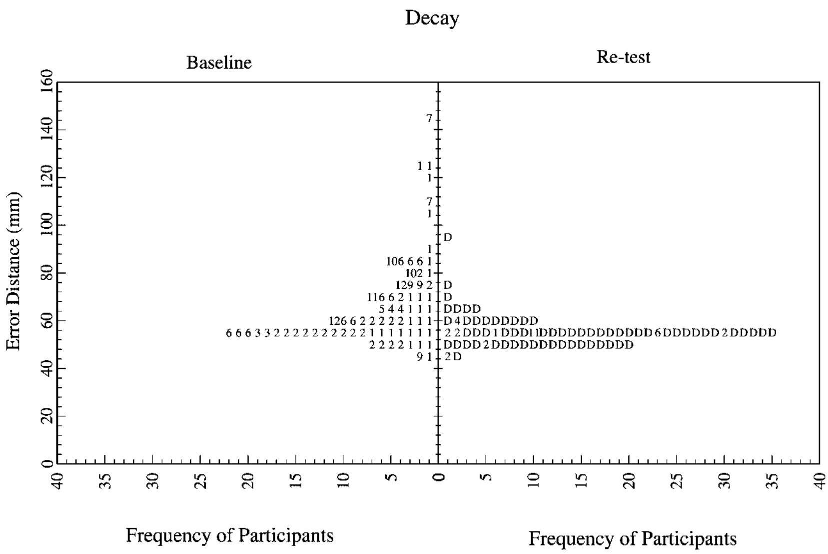

Figure 3. Continued

Hypothesis 4: Can individuals quickly adopt ecologically rational heuristics?

Graphs on the right hand-side of Figure 3 summarize performance after training and so can be used to identify whether participants adopted the heuristics we introduced and whether these were responsible for the observed improvement in performance. A comparison of the left and right graphs in the top panel of Figure 3 suggests that participants in the Control group made no changes to the heuristics they used to make predictions across the two phases, and, consequently, there is little change in the distribution. Indeed, in the absence of an intervention, 93% of participants in the Control group used the same heuristic in both phases. A comparison of the left and right hand-side graphs in the middle panel of Figure 3 indicates that 85% of the participants introduced to the Circle heuristic during training report using the Circle heuristic during re-test (indicated by the letter 'C' in the right graph). Similarly, a comparison of graphs in the bottom panel of Figure 3 indicates that 88% of the participants introduced to the Decay heuristic during training report using the Decay heuristic at re-test (indicated by the letter 'D' in the right graph). For both experimental groups, this change in strategy is accompanied by a downward shift in the distribution of predictions compared to baseline, with those adopting the heuristics falling toward the bottom of the distribution (compare the left and right graphs of the middle and bottom panels of Figure 3). Specifically, 69% of the participants who reported using the Circle heuristic after training showed some improvement in their mean predictive accuracy. Similarly, 78% participants who reported using the Decay heuristic after training showed some improvement in their accuracy across the maps. These findings suggest that participants adopted the introduced heuristics and that adopting the heuristics is associated with an improvement in average predictive accuracy for approximately 75% of participants.

DISCUSSION

Although recent research has indicated that individuals may be able to draw on cognitive heuristics to make accurate predictions, a debate continues as to whether these predictions can reach the levels of accuracy reported for actuarial systems. The current findings shed light on this debate, showing that participants trained in simple cognitive heuristics can perform as accurately as a leading actuarial technique when predicting the location of an offenders' residence based on the locations of their crimes.

Results from the aggregate level analysis showed that participants informed about the Circle or Decay heuristic improved their predictions of offenders' residences to a level of accuracy that was not significantly different from the actuarial technique. Consistent with the findings of Snook et al. (2002), these results indicate that certain cognitive heuristics are effective for this particular real-world prediction task. Interestingly, the findings indicate that teaching one heuristic is sufficient to improve performance, suggesting that there is a considerable degree of overlap between the Circle and Decay heuristics.

Despite this similarity in performance, the Circle and Decay heuristics are not qualitatively identical since predictive accuracy in each of the experimental groups was not consistent across the 10 maps. Specifically, the results showed that participants in the Circle group were, on average, equal to or better than the actuarial technique for five of 10 maps, while the Decay group showed marginally better performance with equal or improved prediction occurring on seven of the 10 maps. Determining why the Decay heuristic led to superior performance is an avenue for further exploration, but it is likely to be the result of a combination of factors including the degree of applicability, the clarity of definition, and the degree of match to the structure of offender spatial behaviour. A detailed comparison of the effectiveness of different heuristics is likely to require more precise definitions of the cognitive heuristics, as has been achieved by using mathematical definitions in other areas (Gigerenzer et al., 1999).

A second implication of the aggregate level results is to question why, on some of the maps, the heuristics had very little impact on participants' predictive accuracy. One important explanation relates to the different types of offender spatial behaviour that characterize this group of serial offenders. For example, a number of studies have shown that a minority of serial offenders do not live near their crimes and that the spatial behaviour of these 'commuter' offenders is not effectively predicted by the Circle or Decay heuristic. For instance, Lundrigan and Canter (2001) found that 11% of US and 14% of UK serial murders were commuters (they lived outside a circle defined by their crime site locations). Since the heuristics we presented were based on the concepts of distance-decay and the circle hypothesis, the lack of improvement on some maps may reflect instances of commuter offenders. If the different behavioural pattern of commuters is the cause of poor performance, neither current actuarial strategies nor the heuristics taught in the current study can claim to be useful (i.e. ecologically rational) in solving the profiling task for all serial offences.

The ideographic analysis of the sorts of strategies that participants were using revealed that a subgroup of individuals employed ecologically rational heuristics to make their predictions prior to training. How individuals learn these heuristics is not made clear by the current experiment. Participants may have drawn upon direct experience with offenders, or they could have learned the heuristics passively through exposure to the media or other educational material.

More generally, these results suggest that the heuristics reported in this study might be part of a more general 'error minimisation' strategy. For instance, it might be the case that individuals use information and knowledge about their own experiences, when attempting to minimize the time and effort expended in traversing the physical environment, to make predictions about other peoples' spatial behaviour (Zipf, 1949). Indeed, research has shown that the same patterns of spatial behaviour that characterize offenders are also evident in consumer behaviour, mate selection, and migration (Olsson, 1965; Taylor, 1974). As Hertwig, Hoffrage, and Martignon (1999) have noted, these patterns that resemble inverted 'J' distributions, where many more small values occur relative to larger ones, are observed across a whole range of activities and phenomena. One approach to identifying the type of experience that enables the development of ecologically rational heuristics for this sort of geographic prediction task would be to test the existence of an association between predictive accuracy and being naturally exposed to offender spatial behaviour. For instance, is it that police officers, through their natural observations of crime site and home locations, develop an understanding of a relationship that facilitates accurate geographic predictions?

The findings from the idiographic analysis further suggest that participants who initially reported using inappropriate heuristics, or those who did not report any strategy, may improve their predictions by adopting heuristics taught during a very short training session. Consistent with other fields of research (Kleinmuntz, 1990), this finding is encouraging since it suggests that the accuracy of geographic predictions may be improved by undergoing some very simple training. However, some proponents of actuarial techniques may dismiss such training as incomplete by highlighting the current procedure as an oversimplified version of the geographic profiling task. For instance, Rossmo (2000) argues that expert geographic profilers must consider not only the location of crime sites but also the underlying topography of the area and other crime scene information (e.g. victim, temporal, and behavioural information). After a prediction using the actuarial technique is completed, the expert geographic profiler processes the additional crime scene information, combines it in some optimal way, and then adjusts the actuarial prediction accordingly.

These claims open up the possibility that providing more information about an offence series might lead to better human geographic predictions. Alternatively, there is evidence in other fields that providing more information might only increase peoples' confidence when making such predictions and not their predictive accuracy (Oskamp, 1965). Further research on this issue will likely consist of designing experimental conditions that are more representative of geographic profiling in an applied police context, particularly with regard to including topographical, behavioural and temporal information. A second possibility is that providing additional information to human judges (e.g. the number of crimes that need to be considered) may increase task complexity to a point where actuarial techniques are necessary. Indeed, actuarial techniques that are able to take account of detailed information such as land use patterns might be able to outperform human judges, both in terms of reliability and accuracy.

Lastly, the findings reported in this study clearly open up the question about the ability to use simple cognitive heuristics to make other sorts of predictions in the forensic context. The use of heuristics is likely to branch across many police prediction tasks such as comparative case analysis (Bennell & Canter, 2002) and anticipating the likelihood of negotiation success in hostage crises (Taylor, 2002). By taking a step back to basics, it may become clear that prescriptions for actuarial techniques may be unwarranted and that individual's heuristic-led judgements may suffice without significant loss in accuracy or effectiveness.

The findings presented in this paper might surprise those researchers and software developers who have assumed that human decision-making is limited and that accurate geographic predictions require actuarial support, extensive training, or both (Canter et al., 2000; Rossmo, 2000). In terms of actuarial support, the present findings suggest that individuals using simple heuristics can make accurate predictions. Indeed, the present findings suggest that technological advances in the field of geographic profiling over the last 10 years may have overcomplicated what may, in reality, be a relatively simple task. Furthermore, in terms of training, the present findings indicate that the police may be able to suffice with a quick and inexpensive training exercise that teaches their officers simple decision rules. The significance of this implication increases with smaller police agencies that are typically limited in technological capabilities. These forces will likely find low-cost easy-to-implement alternatives to geographic profiling systems particularly beneficial.

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