FULL TITLE: The course of case linkage never did run smooth: A new investigation to tackle the behavioural changes in serial car theft

SHORT TITLE: The behavioural case linkage of serial car theft

Davies, K., Tonkin, M., Bull, R., & Bond, J. W.

Key words: case linkage, linkage analysis, behavioural consistency, behavioural distinctiveness, serial offenders, car theft.

Abstract

This study aimed to investigate the case linkage principles, behavioural consistency and distinctiveness, with a sample of serial car thieves. Target selection, acquisition and disposal behaviours, as well as geographical and temporal behaviours, were examined. The effects of temporal proximity and offender expertise were also investigated as moderating factors of behavioural consistency. As in previous case linkage research, geographical and some target selection behaviours were able to predict whether crimes pairs are linked or unlinked at a statistically significant level. Crucially, it was also found that temporal behaviours demonstrate a significant capability to predict linkage status, a variable which has never before been applied to the prediction of linkage in serial car theft. Furthermore, it was demonstrated that changing the operationalisation of the behavioural domains can affect the results obtained. No support was found for the moderation of behavioural consistency based on temporal proximity or expertise. Overall, the results support previous case linkage studies, furthering their practical applicability within the criminal justice system.

Introduction

Case linkage is the prediction of whether a series of offences have been committed by the same perpetrator, based on behaviours demonstrated at those crimes. Recently, it has been posited that case linkage can be of practical benefit within the criminal justice system, and there is growing empirical evidence to support its use during police investigations (Woodhams, Hollin, & Bull, 2007). For example, research on case linkage has the potential to inform the development of tools like the Violent Crime Linkage Analysis System (ViCLAS; Collins, Johnson, Choy, Davidson, & McKay, 1998), and to assist the police in using their resources in the most efficient manner (Woodhams et al., 2007). Furthermore, the more research conducted on case linkage, the better satisfied are the criteria that guide the acceptance of scientific research in court, according to Rule 702 of the Federal Rules of Evidence.

The theory of case linkage

The theory of case linkage is founded in personality psychology (Woodhams et al., 2007). Following the recognition of a lack of evidence for enduring personality traits (Shoda, 1999), it was posited that the fluctuation in behaviour could in itself be an important feature of personality (Mischel & Shoda, 1995). It was suggested that behaviour is subject to change depending on the situation, but that these changes will be consistently manifested when faced with the same or similar situations (Mischel, 1999). Furthermore, it is suggested that one person's reactions to a set of situations will be consistent, and at the same time distinctive from another person's behaviours in those same situations (Mischel & Shoda, 1995). This

social-cognitive theory of personality encapsulates the fluctuations in our behaviour as meaningful changes rather than unwanted variance, and by doing so demonstrates that, if the situation is taken into consideration, then our behaviour can be both consistent and distinctive (Mischel & Shoda, 1995).

These principles of behavioural consistency and distinctiveness are the two underlying assumptions upon which case linkage is based (Bennell & Canter, 2002). Within a forensic context, an offender's behaviour must be both consistent within their own crime series, and the behaviour demonstrated within that crime series must be different from that exhibited by another offender, in order for the behavioural case linkage of crime to be successful. Evidence for these two principles was first established in non-criminal situations (Furr & Funder, 2004; Shoda, Mischel, & Wright, 2004), and research has since established that these principles exist to some extent in the criminal behaviour of offenders (Bennell & Jones, 2005; Markson, Woodhams, & Bond, 2010; Tonkin, Grant, & Bond, 2008).

Case linkage research to date

Recent case linkage research has investigated various behaviours that may be of particular use when linking offences. Behaviours demonstrated at the crime scene, or *modus operandi* (MO) behaviours (Grubin, Kelly, & Brunsdon, 2001; Woodhams & Teye, 2007), geographical behaviours, such as the intercrime distance (Markson et al., 2010; Santtila, Laukkanen, & Zappala, 2007; Tonkin et al., 2008), and temporal behaviours (Goodwill & Alison, 2006; Markson et al., 2010), have all been shown to demonstrate statistically significant levels of behavioural consistency, distinctiveness, and discrimination accuracy.

Case linkage research, drawing again on personality theory, has also suggested variables that may moderate behavioural consistency (Woodhams et al, 2007). It has been posited, for example, that events that happen closer together in time will show greater behavioural consistency than those that happen further apart (Pervin, 2002). As such, it seems logical to suggest that crimes committed with greater temporal proximity will show greater behavioural consistency. While some studies have demonstrated support for this moderator of consistency (Grubin et al., 2001), others have found less promising results (Markson et al., 2010; Tonkin et al., 2008; Woodhams, Hollin, & Bull, 2008; Woodhams & Labuschagne, 2011).

Similar to temporal proximity is the concept of expertise. It is suggested that experience will aid behavioural control as a person gets more familiar with a particular situation (Hettema & van Bakel, 1997). In a criminal context, there are two competing hypotheses. First, it might be hypothesised that as an offender becomes experienced in committing a particular type of crime they refine and specialise their MO, thus leading them to behave in a progressively more consistent and distinctive manner. Alternatively, researchers have discussed the possibility that offenders mature and change their offending patterns over time (Davies, 1992). It has been suggested, for example, that the initial motivations for car theft are often expressive, such as joy-riding, but with experience the incentive to steal cars becomes more instrumental in nature (stealing cars to sell on for profit; Webb & Laycock, 1992). From this perspective, a relationship between expertise and behavioural consistency might not necessarily be expected. Indeed, when the empirical evidence is examined, there is little support for the relationship between behavioural consistency/distinctiveness and expertise (Snook, 2004; Tonkin et al., 2008). One recent study, however, did find a positive relationship between the offending experience of South

African serial rapists and the consistency of their offending behaviour (Woodhams & Labuschagne, 2011).

The current study

While crimes such as burglary, rape, and sexual assault have received considerable attention in the case linkage literature (e.g. Bennell & Canter, 2002; Santtila, Junkkila, & Sandnabba, 2005), car theft has received much less attention.

Car theft deserves the attention of case linkage researchers, however, because it represents a significant problem for police forces in the United Kingdom (UK) and abroad, with 115,000 cars stolen in the UK during 2009-2010 (Flatley, Kershaw, Smith, Chaplin, & Moon, 2010). Furthermore, the British Crime Survey in 2000 found that 46% of victims of vehicle-related theft were emotionally affected either very much or quite a lot, a figure very similar to the 47% of people who felt very or quite emotionally affected at being the victim of a violent crime (Kershaw et al., 2000). Focus should, therefore, be given to volume crime, not just because of the high number of offences, but also because they have an often overlooked emotional effect on the victim.

It is, therefore, surprising that only one previous study has investigated the behavioural case linkage of serial car theft (Tonkin et al., 2008). The need for such research is even greater when one considers that Tonkin et al. (2008) only sampled crimes that were explicitly recorded as car thefts on the police database. As demonstrated by Davies, Bond, and Smith (2011), 48.7% of crimes classified as domestic burglaries where a car was stolen should actually have been classified as a car key burglary (where an offender breaks into a residence with the specific intention of stealing the car keys). Given that Tonkin et al.'s

(2008) sample included only those crimes specifically recorded as car thefts within the police database, they did not identify those car thefts that may have been misclassified due to the nature of the theft. As a consequence the sample studied by Tonkin and colleagues could be considered incomplete.

The omission of car key burglaries within a sample of car thefts is an issue that is becoming ever more pertinent, given that the advancement in vehicle security measures, such as the introduction of mandatory immobilisers in cars, has meant an increase in the theft of car keys in order to steal the vehicle (Shaw, Smith, & Bond, 2010). Not only did the current study aim to investigate the principles of behavioural case linkage with a new dataset, it also included a full sample of car thefts, including the increasing number of car key burglaries that may have been misclassified as domestic burglaries.

Another important aim of the current study was to explore whether changes to the way that behaviours are operationalised in case linkage research can yield more successful discrimination accuracy. The way that behaviour is operationalised within case linkage studies is integral to their findings, and unless different methods are investigated then it is not possible to empirically state their use in linking crimes. Temporal behaviour is a good example of how changes to the way in which behaviour is operationalised can substantially impact on discrimination accuracy. When temporal behaviour has been operationalised as a series of time bands (e.g. Tonkin et al., 2008) it has demonstrated a limited ability to distinguish between linked and unlinked crimes. When this behaviour has been operationalised as a continuous, independent variable, however, it has shown statistically significant discrimination accuracy (Markson et al., 2010). Therefore, researchers cannot reject any potential linkage features until they have been operationalised and tested in a

variety of ways. This study, therefore, investigated whether the difference in the way that the behaviours were measured affected their subsequent importance in linking crimes.

Previous research has found that the intercrime distance (the distance between the theft locations of stolen vehicles) and the interdump distance (the distance between the stolen vehicles' recovery locations) can be used to effectively predict whether car thefts are linked or unlinked (Tonkin et al., 2008). It has not yet been investigated, however, whether temporal distance (the number of days between the car thefts) can be used to discriminate between linked and unlinked offences. This might be predicted given the discrimination accuracy of temporal behaviours seen with other crime types, such as residential burglary (Markson et al., 2010; Tonkin, Santtila, & Bull, 2011). This study aimed to test the intercrime, interdump, and temporal distances between car thefts, hypothesising that all three variables would be useful in the prediction of case linkage. It also aimed to test another, new variable, the value of the car stolen, in order to examine its ability to successfully predict case linkage.

Finally, the current study also addressed the issue of whether temporal proximity and offender expertise would moderate the level of behavioural consistency displayed by serial car thieves.

To summarise, the current study had four main aims:

- 1) To examine case linkage with serial car theft using a more comprehensive sample of car thefts (including both car key burglaries and 'traditional' car thefts).
- 2) To explore whether discrimination accuracy can be improved simply by changing the way behavioural domains are operationalised during case linkage research.

- 3) To examine those behaviours which have not yet been investigated in relation to serial car theft; the temporal distance between crimes and value difference of the cars stolen.
- 4) To further examine the impact of temporal proximity and offender expertise on behavioural consistency in serial car theft.

Method

The sample

The study was based on data collected from the Northamptonshire Police Force in the UK, and included crimes committed in a four-year period ranging from 1st June 2007 to 1st June 2011. A search to find all car thefts was conducted by selecting the following crimes, including only those where a vehicle registration was present: theft in a dwelling, theft from the person, theft of a motor vehicle, robbery/personal property, burglary in a building (not dwelling), burglary in a dwelling, and aggravated taken without consent (TWOC). Any vehicles other than cars or vans were deleted from the sample, because of the different security measures used to protect these types of vehicles from theft (Tonkin et al., 2008). Each car theft that was included in the sample was classed as ‘detected’ by the police; that is to say that an individual had either confessed to the crime, or there was enough witness or forensic evidence for the police to consider the case to be solved.

The sample was refined using the police database’s free text MO box. This was used to ensure that no duplicates or wrongly reported crimes were included within the sample. If more than one car had been stolen in a single crime, then one was randomly deleted. Crimes were also deleted if two offenders had committed the same two crimes, to avoid duplication

of linked pairs. Finally, in cases where a car had been stolen as part of a burglary, the information in the free text MO box was used to determine whether the car had been targeted in a car key burglary. According to previous research on car key burglary (Shaw et al., 2010), actions such as a tidy search of the house were indicative that a car key burglary, as opposed to a domestic burglary, had taken place, and these findings were used along with common sense judgement (e.g. ‘offender has stolen the car key from the house, using an implement to hook the key through the letterbox from inside the house’ was deemed to be a car key burglary, as it was apparent that the car keys were the intended target) in order to make a decision about whether or not the burglary was in fact a car key burglary.

Finally, the two most recent crimes per offender were selected, as is consistent with the methodology employed by Tonkin et al. (2008). While crimes series ranged from 2 to 33, pairs of offences were chosen for analysis because the majority of offenders had committed only two crimes (50%). The final sample consisted of 258 pairs; 129 linked pairs, and 129 randomly generated unlinked pairs.

Procedure

For each of the 258 crime pairs in the sample a variety of behavioural, geographical, and temporal information was extracted from the police force database. While the accuracy of information collected by the police could not be assessed at the level of input, police officers use a comprehensive data collection system which is designed to gather as much detailed information as possible. The behavioural variables used in this study were based on Tonkin et al.’s (2008) choice of potential linking features, and were coded into each domain according to the coding system used in this previous case linkage research. The behavioural domains of target selection, target acquisition and disposal remained, as well as intercrime and interdump

distance. A new target selection variable was added, as well as the addition of new, continuous variables; the temporal distance between crimes, and the age and value differences between the stolen vehicles.

Several of these new domains were sampled in addition to those previously used by Tonkin et al. (2008), in order to investigate how the operationalisation of behavioural domains may impact on their ability to predict case linkage. First, the age of vehicle was used to create a new, continuous variable reflecting the difference in age of the two vehicles stolen in each linked and unlinked pair. This is in contrast to previous studies, where age has only been included in the target selection domain as a categorical variable. Second, several target selection variables were sampled in the current study that were not investigated by Tonkin et al. (2008) to form a second, new target selection variable. Within this domain, whether the stolen vehicle had a built-in immobiliser, and the type of theft, a ‘traditional’ car theft or a car key burglary, were both measured, recognising a previously overlooked differentiation in car theft MO. Whether the owner of the vehicle was known to the offender was also included.

Due to improvements in vehicle security since Tonkin et al. (2008), many more offenders were forced to access the vehicles using stolen keys. These changes in offender behaviour necessitated changes to the target acquisition domain in this study (see Table 1). Furthermore, several of the variables included in the disposal domain by Tonkin et al. (2008) were amalgamated into broader variables due to a lack of sufficient information in the crime reports. A breakdown of the behaviours coded into the four domains target selection old, target selection new, target acquisition, and target disposal are shown in Table 1.

INSERT TABLE 1 HERE.

The geographical behaviours, intercrime and interdump distance, were measured using www.bing.com/maps in order to generate the shortest road route distances between site of theft postcodes and between car recovery location postcodes. The website www.timeanddate.com was used in order to establish the number of days that had elapsed between the two crimes, establishing the temporal distance between each pair of car thefts. The ages of the cars were calculated using the vehicles' registration plates. The values of the cars were calculated by generating an average price of cars of the same make, model and type advertised on www.autotrader.co.uk. If no exact match could be found then cars within a year of the actual age were used on which to base an average price (or, in the few circumstances where similar older cars made before 1995 could not be found then cars within three years of the actual age were used), or alternatively cars of the nearest type and same age to that of the sample car. The differences between the ages and values of each pair of cars were then calculated.

Jaccard's coefficients were calculated for the target selection (old), target selection (new), target acquisition and target disposal domains. Jaccard's coefficient is a measurement of similarity that ranges from 0 (indicating no behavioural similarity) to 1 (indicating complete behavioural similarity). It is a commonly used measure of similarity in case linkage research because it ignores joint non-occurrences in behaviour (Bennell & Canter, 2002). The Jaccard's coefficients, spatial and temporal distances, and car age and value differences were used as the basis for subsequent analysis.

In order to investigate the effect of temporal proximity on behavioural consistency, the sample of 129 linked pairs was split into four groups, constructed on the basis of equal

sample size, depending on the number of days separating the crimes in each pair. Group 1 contained pairs separated by 0 to 10 days ($N = 33$, $M = 2.42$ days), Group 2 = 11 to 80 days ($N = 33$, $M = 31.45$ days), Group 3 = 81 to 400 days ($N = 32$, $M = 210.72$ days), and Group 4 = greater than 400 days ($N = 31$, $M = 679.77$). Using Jaccard's coefficients calculated from all MO behaviours in each pair in order to establish behavioural consistency, analyses were then undertaken in order to investigate potential differences between the groups.

In order to test the effect of expertise on behavioural consistency, the ten most prolific offenders were identified, who were responsible for crime series ranging from 9 to 33 crimes. In line with the methodology first proposed by Woodhams et al. (2007), and more recently used by Tonkin et al. (2008), the two earliest and two latest crimes from these series were selected, resulting in ten pairs of the earliest and ten pairs of the latest crimes committed by these offenders. Similarly to temporal proximity, behavioural consistency of the pairs was established by calculating Jaccard's coefficients using all MO behaviours, as well as calculating the intercrime, interdump and temporal distances between each crime pair. Differences between these pairs were then investigated in order to establish whether offenders' expertise affects their behavioural consistency.

Results

Testing the principles of case linkage

The principles of case linkage, behavioural consistency and distinctiveness, were tested using Wilcoxon matched-pairs signed ranks tests, binary logistic regression analysis, and Receiver Operating Characteristic (ROC) analysis.

Behavioural consistency of the behavioural domains target selection (old), target selection (new), target acquisition and target disposal was tested using a Wilcoxon matched-pairs signed ranks test. This non-parametric test was chosen because the data were non-normally distributed, as indicated by a Kolmogorov-Smirnov test ($p < 0.01$).

For the target selection (old), target selection (new) and target acquisition domains, the linked crime pairs demonstrated significantly greater behavioural consistency than the unlinked crime pairs. In the disposal domain, the linked and unlinked crime pairs did not significantly differ in their behavioural similarity (see Table 2).

INSERT TABLE 2 HERE.

Before conducting further analysis, the sample was split into two datasets. This was done because of the problems associated with developing and testing regression models on the same sample (Bennell & Canter, 2002). A training sample containing 65 linked and 65 unlinked pairs was used to conduct binary logistic regression analysis, while a test sample of 64 linked and 64 unlinked pairs was set aside to be used in later analysis.

Each behavioural domain was first entered separately into a direct binary logistic regression analysis to see whether it could independently discriminate between linked and unlinked crime pairs. An optimal model was then constructed using forward stepwise logistic regression analysis, where all domains were entered simultaneously into the analysis. Target selection (old), target selection (new), target acquisition, target disposal and temporal distance contained complete data sets of 130 pairs, while missing data meant that the

following behavioural domains were smaller: intercrime distance = 117 pairs, interdump distance = 68 pairs, age difference = 127 pairs, value difference = 116 pairs.

Prior to these analyses the assumptions of logistic regression were examined, with no violations observed. The independent regression models containing intercrime, interdump, and temporal distances demonstrated a highly significant ability to predict linkage status (whether crime pairs were linked or unlinked; see Table 3). The independent regression models containing target selection (old), target selection (new), target acquisition, target disposal, car age difference and car value difference were all non-significant, demonstrating these behaviours' lack of ability to accurately predict linkage status. The stepwise regression model contained four variables, intercrime distance, temporal distance, target selection (new), and target acquisition behaviours. Given the significance of the independent regression models including intercrime distance and temporal distance, it would appear that these variables played a fundamental role in the formulation of this optimal model; the inclusion of target selection (new) and target acquisition behaviours suggests that these variables may be of predictive value when used in conjunction with other variables.

INSERT TABLE 3 HERE.

The logit coefficients were positive for the MO behavioural domains, demonstrating that the more similar the behaviours were, the more likely it was that the cases were linked. Negative logit coefficients for intercrime, interdump and temporal behaviours demonstrated that the smaller the distance between the two variables, the more likely it was that the crimes were linked. There was a negative logit coefficient for age difference, indicating that the closer two cars were in age; the more likely they were to have been stolen by the same

person. The regression model for age difference, however, was non-significant, demonstrating that including age as a continuous rather than a categorical variable did not increase its predictive power.

In terms of predictive performance, those regression models that demonstrated an ability to improve the classification of pairs as linked or unlinked compared to the level expected by chance were the optimal model (with a 32.70% improvement), intercrime distance (24.80%), interdump distance (22.10%), temporal distance (14.60%), and target selection (new) (10.00%; see Table 4).

INSERT TABLE 4 HERE.

A fundamental assumption of logistic regression is that the errors should be independent of each other. Consequently, the samples used should be independent, but as the unlinked pairs were generated from the linked pairs this is not the case (Bennell & Canter, 2002). Whereas the violation of this assumption can influence the predictive accuracy of logistic regression, it does not influence the measures of accuracy produced using ROC analysis because it does not rely on estimates of the standard error in the same way as tests such as logistic regression (Bennell & Canter, 2002). The logistic regression models produced for the training sample were applied to the test sample using a methodology as described in Bennell and Canter (2002), in order to provide predicted probability values that were used in the subsequent ROC analysis. ROC curves were generated for each of the nine behavioural domains, and a tenth curve was generated for the optimal model (see Figure 1).

INSERT FIGURE 1 HERE.

Target disposal and car value difference, as in the regression analyses, showed discrimination accuracies that were not statistically greater than chance (see Table 5). Car age difference, target selection (old), and target acquisition showed only low levels of predictive accuracy according to published standards (Swets, 1988). All three variables that significantly predicted case linkage in the independent regression analyses, (intercrime distance, interdump distance, and temporal distance), along with target selection (new) (which was included in the optimal regression model), and the optimal model achieved moderate to high levels of discrimination accuracy, with areas under the curves (AUCs) all above 0.70 (Swets, 1988). Contrary to the regression analyses, however, interdump distance outperformed temporal distance in the ROC analyses. This would suggest that all of these variables should be taken into account when attempting to link crimes. This suggestion is furthered by the overlap in the confidence intervals of the interdump and temporal distance ROC curves, indicating that caution should be used when inferences are drawn about which variables outperform the others.

INSERT TABLE 5 HERE.

Calculating decision thresholds – practically applying the theory

Using Youden's index it is possible to identify a threshold that maximises the number of correct linkage decisions and minimises the number of incorrect decisions (Bennell & Canter, 2002). The practical advantage of creating this decision threshold is that they can be related back to 'real-life' data, e.g. the creation of a decision threshold of 2.5km, as opposed to $p < 0.05$.

Following the calculation of the ROC curves, Youden's indices were calculated for the four variables that demonstrated high levels of predictive accuracy, using the following formula:

$$J = pH + pCR - 1$$

J = Youden's index

pH = probability of correctly identifying a linked pair

pCR = probability of correctly rejecting an unlinked pair.

The Youden's indices calculated were then plotted against the various decision thresholds, in order that the highest point on the graph (a potential decision threshold at which to consider crimes linked) could be identified.

INSERT FIGURE 2 HERE.

By identifying the highest points on these graphs the decision thresholds that maximised the number of correct linking decisions were identified (Bennell, 2002). These potential decision thresholds and their equivalent 'real-life' values were as follows; intercrime distance = 0.59, 10.55km; interdump distance = 0.52, 15.00km; temporal distance = 0.60, 227 days; target selection (new) = 0.55, Jaccard's coefficient of 0.83. These decision thresholds suggest that cars stolen within 10.55km of each other, that were dumped less than 15.00km apart, that occurred within 227 days of each other, and that have a target selection (new) Jaccard's coefficient of more than 0.83 should be considered potentially linked. However, Youden's index does not take into account certain factors that should be addressed when attempting to create true optimal decision thresholds; for example, the costs and benefits associated with all outcomes, or the prior probabilities of linked and unlinked crimes.

The limitations of Youden's index should be considered, and are discussed elsewhere in more depth (see Bennell, 2002; Tonkin, Woodhams, Bull, Bond, & Palmer, 2011).

Conditions of consistency

Two of the four groups of linked pairs that were described above in the Procedure section were not normally distributed, as indicated by Kolmogorov-Smirnoff tests ($p < 0.05$). But, ANOVA is robust against violations of normality when sample sizes are similar (Field, 2009).

Preliminary analyses revealed that the four groups of linked crime pairs (as described in the Procedure section above) were significantly different in terms of temporal proximity, indicating that the partitioning procedure had successfully split the pairs into distinct groups that differed in terms of their temporal proximity. Further analysis to investigate the impact of temporal proximity on behavioural consistency was, therefore, justified.

A one-way independent ANOVA was used to assess whether there were any differences in behavioural consistency dependent on temporal proximity of the crimes in each pair. Levene's test was non-significant, $F(3, 125) = 0.48, p = 0.70$, indicating homogeneity of variance. No significant difference was found between any of the groups, $F(3, 125) = 1.37, p = 0.25, r = 0.12$, indicating that the number of days between the crimes in each pair had no significant effect on behavioural consistency.

In order to examine whether offenders' expertise had an effect on behavioural consistency, Jaccard's coefficients were generated for all MO behaviours, as well as intercrime, interdump, and temporal distances, between the first two and last two crimes from

the series of the ten most prolific offenders. Scores were then compared between the earliest and latest crime pairs, in order to establish whether offenders' behavioural consistency had changed over time. Assumptions of normal distribution were met in two of the variables, MO behaviours and intercrime distances ($p > 0.05$), so paired-samples t -tests were used for these analyses. Interdump distances and temporal distances were not normally distributed ($p < 0.05$), so the non-parametric equivalent, the Wilcoxon signed-rank test, was used. It was found that expertise had no effect on behavioural consistency of MO behaviours, $t(9) = 0.83$, $p = 0.43$, $r = 0.19$; intercrime distance, $t(8) = -0.44$, $p = 0.67$, $r = -0.10$; interdump distance, $Z = -1.10$, $p = 0.27$, $r = -0.31$; or temporal distance, $Z = 0.97$, $p = 0.33$, $r = 0.22$.

Discussion

Demonstrating the principles of case linkage

Both the principles of behavioural consistency and distinctiveness were supported in the current study, with intercrime distance, interdump distance, temporal distance, and target selection (new) behaviours demonstrating statistically significant discrimination accuracy. The hypothesis that geographical behaviours would predict case linkage has been substantiated, further validating the results of previous case linkage research (e.g. Bennell & Canter, 2002; Tonkin et al., 2008; Woodhams & Toye, 2007). These findings also further support the potential value of the interdump distance as a case linkage predictor (Tonkin et al., 2008).

The notion that temporal behaviours would be of significant use in case linkage prediction was also supported, replicating findings observed with residential burglary

(Markson et al., 2010; Tonkin et al., 2011). Car age and value difference, as well as target selection (old) behaviours, target acquisition behaviours, and target disposal behaviours, however, all showed low levels of discrimination accuracy. These results are similar to those found by Tonkin et al. (2008).

This study also asked two broader research questions, (i) whether modifying the way some behaviours were measured would make them more useful in the prediction of case linkage, and (ii) whether adding different behaviours would also improve predictive performance. In terms of modifying behaviours, there was limited success. Specifically, it was found that converting the car age bands studied by Tonkin et al. (2008) to a continuous measure of car age difference did not result in a substantial improvement in discrimination accuracy. In terms of adding new behaviours, however, there was relatively more success. Temporal distance was found to demonstrate significant discrimination accuracy, as discussed above. Furthermore, the new target selection domain demonstrated a higher level of predictive accuracy than the old target selection domain that was studied by Tonkin et al. (2008). It should be noted, however, that while the target selection (new) domain demonstrated significant results using ROC analysis, the regression model including this variable was non-significant. This could imply that this variable may not consistently demonstrate the ability to predict case linkage.

These findings regarding the modification of behavioural domains are important because they demonstrate that discrimination accuracy is inherently tied to the way in which behaviours are operationalised for use in case linkage research, and that there is scope for the improvement of these domains' predictive potential by coding them differently or by sampling different behaviours. Case linkage researchers should, therefore, exercise caution

when making recommendations to the police regarding which behaviours should and should not be used for the purposes of case linkage until different methods of operationalising these variables have been investigated. Research cannot recommend that certain domains are not used in case linkage until these issues have been thoroughly explored.

Although the present study supports the results found in Tonkin et al.'s (2008) study on car crime, the differences between the two sets of results must also be highlighted. The present study found that disposal behaviours failed to find a significantly greater amount of behavioural consistency in linked pairs. However, it was difficult at the time of coding the data to find enough detail in order for this domain to be used. This does, perhaps, show the progression of the police force's data collection. The fact that the majority of the intercrime distance data were present could suggest that there is already an emphasis on the collection of the data that are helpful when looking to link crimes.

In terms of the underlying theory of case linkage, the present results support the concept that the behaviours that are under an offender's control are those that are most consistent (Bennell & Jones, 2005). As cars are to be found on the majority of streets and driveways, the decision of when and where to steal a car should be almost completely within an offender's control. The results also support the notion that offenders operate in areas that they are familiar with; the intercrime and interdump distances being shorter for linked compared to unlinked pairs (Markson et al., 2010; Santtila, et al., 2007). As Tonkin et al. (2011) explain, these findings fit with several seminal theories of offender spatial behaviour, which suggest that offenders seek to minimise the efforts and risks involved in offending (e.g. by returning to the places that are familiar to them and by not travelling great distances to

offend; e.g. Brantingham & Brantingham, 1981, 1984; Clarke & Felson, 1993; Cohen & Felson, 1979).

Alternatively, the relatively greater success with the spatial and temporal behaviours may be due to these data being easier to store and code reliably (Bennell & Jones, 2005). Postcodes and dates are simple and reliable facts to record accurately, whereas the method of entry into a vehicle, for example, relies on the observation of the attending officer, and their decision as to which facts are deemed relevant or important enough to record. As previously intimated, it may be that police officers place a greater importance on recording those behaviours which are subject to less personal interpretation, and as such spatial and temporal behaviours are those variables most consistently and reliably recorded.

These results have a practical application in police investigations. The usage of geographical and temporal behaviours should be combined, however, because of the discrepancies noted above between the outcomes of the regression and ROC analyses, and the overlap of the ROC curve confidence intervals. The results also show that types of target selection behaviours and target acquisition behaviours may be useful when used in conjunction with these more proven reliable behaviours.

Conditions of consistency

As in other recent case linkage studies (e.g. Markson et al., 2010; Tonkin et al., 2008), no significant differences were found with regard to the temporal proximities of the crimes, or the expertise of the offenders, in relation to their behavioural consistency. The current study further supports these findings. Measuring the conditions of consistency, however, should be successful only if they are collected and coded appropriately. In this study, for

example, all vehicles other than cars and vans were excluded from the analysis. However, in the original data, thieves would often modulate between stealing cars, motorcycles, and other vehicles, suggesting their criminal attentions were not focused on one type of vehicle. If this is the case, then the ‘true’ first and most recent crimes committed, as well as the ‘true’ time between each pair of crimes becomes distorted on the basis that many equally important crimes in each series have been deleted. Furthermore, police data cannot always be considered reliable, and this unreliability would contribute to noise in the data which may mask important findings concerning the conditions of consistency. Considering the evidence to date, it may be that police data cannot be relied upon to investigate these moderators of behavioural consistency. These findings demonstrate, perhaps, that alternative, more controlled methods of investigation are required if significant results with regards to the conditions of consistency are to be found.

Practical implications of the findings

Importantly, the findings of this study support previous case linkage research, further solidifying the reliability and validity of using geographical behaviours to aid the linking of crimes. Not only did it find support for intercrime distance as a predictor of case linkage, but also for interdump distance, a relatively new variable suggested as an aid to the investigative process. Temporal distance, as in Markson et al.’s (2010) paper, was also found to successfully predict case linkage, further demonstrating this behaviour’s potential value for linking crime.

The current study also provided decision thresholds at which pairs should potentially be considered linked, increasing the practical application of these results to the investigative process. There are discrepancies between the actual values found, however, and those of

previous studies; the intercrime distance at which two crimes should be considered linked, for example, was found to be 10.55km, in comparison to the 4.44km suggested by Tonkin et al. (2008), and the 2.99km found by Markson et al. (2010). It is consequently suggested that these decision thresholds should be used as guidance, rather than empirical fact (Tonkin et al., 2011).

There are two ways that research on case linkage can be used within the criminal justice system; as an aid for police officers during the investigative process, and as evidence in court. Police officers have an ever-building body of research demonstrating that easily-recorded geographical and temporal behaviours could be of great assistance when attempting to attribute several cases to one offender. Furthermore, these findings further add to the growing body of evidence to support the use of case linkage, which helps to satisfy one of the key principles of Rule 702 of the Federal Rules of Evidence, which stipulates that any expert testimony submitted as evidence in court must be based on sufficient facts or data.

The significance of the linking potential of target selection (new) behaviours, while too contentious at present to be used as evidence in court, may be able to provide the police with some assistance in their investigations. The division of car theft based on type of crime (car key burglary or car theft), for example, may act as an important variable when conducting case linkage. The decision as to how to break into a car suggests an element of planning, and planning behaviours have previously been found to successfully predict whether crimes are linked or not (Woodhams & Toye, 2007). As with spatial and temporal behaviours, the significance of these results suggest that behaviours within an offender's control (as is the planning of a crime) are those that are most useful in the prediction of case linkage. At present, this factor does not appear to be appropriately coded within the police

records (Davies et al., 2011); in this instance these results would seem to be of some use in informing the police as to improvements in their data recording.

Limitations of the study

As has been mentioned above, using police data that have not been collected for the purpose of research is always associated with a certain amount of noise, although it has been posited that this only serves to reinforce the reliability and validity of any significant results found (Goodwill & Alison, 2006). Any results found should be treated with a certain amount of caution, however, given the amount of missing data associated with police records. Most crucially, not all crimes committed by one offender will have been recorded, and it is this point that may have had an impact on the ability to find significant results within the conditions of consistency. The selection of the data in this study has also been shown to have an impact on whether significant results can be found. Excluding the theft of other vehicles may have meant excluding valuable data about a particular offender, altering the predictive accuracy of the variables tested.

It is debatable whether this study could be generalised to the wider population of car thieves. Northamptonshire is a semi-rural county with a population density of 290 persons/km². The application of these results to an urban county such as Greater Manchester, for example, with a population density of 2,016 persons/km², may be a little premature.

Case linkage studies rely on solved crimes in order to test known offenders' behaviour during the crimes that they are known to have committed. This, of course, assumes that the behaviours of those offenders who are caught are comparable to those who are not. It may be that the very reason why these offenders are caught is because of their behavioural

similarity (Bennell & Canter, 2002). Furthermore, the classification of a crime as ‘detected’ by the police does not categorically determine an offender’s guilt, and misattribution of particular crimes to offenders introduces another potential degree of error in the data.

Further research

The limitations of the study highlight an obvious need for replication across crime type and location, before the results of this study can be applied in practice. Replicating case linkage results using unsolved crimes, for example, seems crucial (Woodhams & Labuschagne, 2011). Similarly, the differences in behaviour found between burglary types (Bennell & Jones 2005) may demonstrate that the segregation of different types of car theft would lead to a better understanding of the importance of different behaviours in different situations. This would require investigation into the reasons behind car theft; the recent increase in car key burglaries being attributed to professional criminals who steal for financial gain, for example (Warwickshire Police Force, 2003). Future research might, therefore, investigate whether the domains that have the potential to support case linkage differ in car key burglaries compared to ‘traditional’ car thefts.

The conditions of consistency continue to prove difficult to measure. As it has been suggested, perhaps the manner in which they are being investigated is flawed. It is possible that offenders who commit property crimes are indiscriminate about the type of crime they commit, and as such conditions of consistency should be based on all crimes an offender has committed, rather than one type in particular (Tonkin et al., 2011).

Finally, it seems apparent that no behaviour is completely situation-dependent. A greater understanding of those factors that can influence behaviour might increase our predictive accuracy as to which crimes are linked and which are not.

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Tables and Figures

Table 1

Behaviours coded into four car theft domains

Offence Behaviour	Behavioural Domains			
	Target Selection Old	Target Selection New	Target Acquisition	Target Disposal
Type of car				
Hatchback	X			
Saloon	X			
Estate	X			
Van	X			
Coupe	X			
Convertible	X			
Sports	X			
Jeep/Landrover	X			
MPV/People carrier	X			
Age of car				
New (0-3 years)	X			
Middle-aged (3-9 years)	X			
Old (9-15 years)	X			
Very old (15+ years)	X			
Time of day				
0600 – 1359	X			
1400 – 1759	X			
1800 – 2259	X			
2300 – 0559	X			
Day of week				
Monday	X			
Tuesday	X			
Wednesday	X			
Thursday	X			
Friday	X			
Saturday	X			
Sunday	X			

Type of car theft				
Car Key Burglary	X			
Car Theft	X			
Innocent party selection				
Known	X			
Unknown	X			
Immobiliser present				
Yes	X			
No	X			
Method of entry				
Keys (insecure)			X	
Keys (stolen)			X	
Forced entry			X	
Method of starting car				
Using keys			X	
Forced start			X	
Property taken				
No property taken				X
Items taken				X
Vehicle recovery state				
Uncovered				X
Recovered intact				X
Recovered damaged				X
Total behaviours	24	6	5	5

Table 2

Behavioural similarity of the four domains

Mean+ Jaccard's Coefficients				
Variables	Linked	Unlinked	Wilcoxon / <i>Z</i>	Effect Size / <i>r</i>
Target Selection Old	0.27	0.20	-2.46*	-0.15
Target Selection New	0.66	0.46	-4.37**	-0.27
Target Acquisition	0.33	0.13	-4.35**	-0.27
Target Disposal	0.40	0.42	-1.07	-0.07

* $p < 0.05$; ** $p < 0.001$ *Note.* +Mean (as opposed to median) used to better demonstrate the directional difference.

Table 3

Regression analyses to show how successfully the variables predict case linkage

Statistical Output	Model 1: Selection Old	Model 2: Selection New	Model 3: Target Acquisition	Model 4: Target Disposal	Model 5: Intercrime Distance	Model 6: Interdump Distance	Model 7: Temporal Distance	Model 8: Age Difference	Model 9: Value Difference	Model 10: Optimal Model
Constant										
Logit (<i>SE</i>)	-0.20 (0.28)	-0.43 (0.33)	-0.16 (0.20)	-0.26 (0.27)	1.41 (0.33)	0.97 (0.38)	1.08 (0.30)	0.13 (0.29)	0.10 (0.24)	2.37 (1.13)
Wald	0.51	1.73	0.63	0.95	18.02	6.60	12.96	0.18	0.17	4.37
Significance	0.48	0.19	0.43	0.33	0.00	0.01	0.00	0.67	0.68	0.04
Selection Old										
Logit (<i>SE</i>)	0.86 (0.95)									
Wald	0.82									
Significance	0.36									
Selection New										
Logit (<i>SE</i>)		0.77 (0.50)								2.44 (1.45)
Wald		2.42								2.82
Significance		0.12								0.09
Acquisition										4.53 (2.12)
Logit (<i>SE</i>)			0.80 (0.49)							4.55
Wald			2.72							0.03
Significance			0.10							
Disposal										
Logit (<i>SE</i>)				0.67 (0.53)						
Wald				1.65						
Significance				0.20						
Intercrime										
Logit (<i>SE</i>)					-0.10 (0.02)					-0.20 (0.07)
Wald					24.95					9.13
Significance					0.00					0.00

Interdump										
Logit (<i>SE</i>)						-0.06 (0.02)				
Wald						8.21				
Significance						0.00				
Temporal										
Logit (<i>SE</i>)						-0.00 (0.00)		-0.01 (0.00)		
Wald						19.25		6.73		
Significance						0.00		0.01		
Age										
Logit (<i>SE</i>)						-0.03 (0.04)				
Wald						0.67				
Significance						0.42				
Value										
Logit (<i>SE</i>)								0.00 (0.00)		
Wald								1.77		
Significance								0.18		
Model χ^2	0.84	2.49	2.83	1.68	39.56	11.63	25.19	0.67	2.05	42.55
Sig. χ^2	0.36	0.12	0.09	0.20	0.00	0.00	0.00	0.41	0.15	0.00
Nagelkerke R ²	0.01	0.03	0.03	0.02	0.38	0.21	0.24	0.01	0.02	0.72
H&L χ^2	4.97	5.87	6.28	5.81	9.93	10.53	23.67	5.64	11.02	5.95
Sig. H&L χ^2	0.29	0.12	0.01	0.06	0.27	0.23	0.00	0.69	0.20	0.55

H&L = Hosmer and Lemeshow test

Table 4

Percentage of pairs correctly assigned as linked or unlinked by the regression models

	Model 1: Selection Old	Model 2: Selection New	Model 3: Target Acquisition	Model 4: Target Disposal	Model 5: Intercrime Distance	Model 6: Interdump Distance	Model 7: Temporal Distance	Model 8: Age Difference	Model 9: Value Difference	Model 10: Optimal
Random	50.00	50.00	50.00	50.00	50.40	52.90	50.00	51.60	52.60	50.90
Model	55.40	60.00	52.30	48.50	75.20	75.00	64.60	53.20	51.70	83.60

Table 5

A summary of the ROC analyses

Variable	AUC	SE	CI
Selection Old	0.62*	0.05	0.53-0.72
Selection New	0.76**	0.04	0.68-0.84
Acquisition	0.64*	0.05	0.55-0.74
Disposal	0.54	0.05	0.44-0.64
Intercrime Distance	0.91**	0.03	0.85-0.97
Interdump Distance	0.88**	0.05	0.79-0.97
Temporal Distance	0.78**	0.04	0.69-0.86
Age Difference	0.62*	0.05	0.52-0.72
Value Difference	0.56	0.05	0.46-0.67
Optimal	0.92**	0.03	0.89-0.97

AUC = area under the curve

* $p < 0.05$; ** $p < 0.0005$