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Above and below: measuring crime risk in and around underground mass transit systems

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Abstract

This paper explores crime risk within and around major transit systems, specifically by investigating theft of personal property offences on the London Underground. The majority of studies to date have examined theft *above* ground, predominantly at transit stations, although some studies have compared this with theft in nearby surrounding areas. This study is unique and extends this analysis to theft during transit journeys *below* ground. The location of such offences is often unknown, only discovered by the victim sometime after the event. A new technique termed Interstitial Crime Analysis is used to better measure the location of *below* ground theft offences; these are compared with *above* ground thefts using Spearman's Rank tests for association. Key findings are: *below* ground theft offences are concentrated at particular stations; risk is highest during morning and late afternoon peak travel periods; at these peak times there is an elevated risk of theft at both high risk stations and in their surrounding environs; and that this relationship is not evident during the inter-peak and late night time periods. The findings suggest offenders who operate below ground may also operate above ground on major transit systems. This has clear policy implications for policing these settings and highlights the importance of joint operations and information sharing between transit agencies and local police forces operating near major transit systems.

Keywords: Theft; Pocket-picking; Underground; Subway; Interstitial crime-analysis; Mass transit systems; Public transport

Background and context

This empirical study examines theft from person offences on underground mass transit systems. Four potential settings of theft are identified; in the vicinity of a station but outside its boundary; inside a station boundary before the paid access barrier; within the paid access barrier outside of carriages, and; inside a rail carriage. For the purpose of this paper the first two settings are described as *above* ground settings and the latter two as *below* ground. This paper examines theft at these different settings, in order to gain a better understanding of risk. Specifically, the aim of this paper is to explore whether there is a transmission of theft risk, from outside the transit system *above* ground, to inside the transit system *below* ground, and vice versa.

The research evidence here is mixed. On the one hand, studies have asserted that the impact of a well-designed secure transit hub, is to actually insulate itself from surrounding high crime risk environments (Clarke et al. 1996; La Vigne 1997). In direct contrast, other studies have found that transit hubs with the highest levels of crime tend to be situated within high-crime areas (Block and Block, 2000; Loukaitou-Sideris et al. 2002; Newton, 2008, Ceccato et al. 2011). No studies to date have examined this for theft from person offences, and this study explicitly addresses this research gap.

In order to carry out this research however, it is necessary to introduce a new technique, *Interstitial Crime Analysis* (ICA). This is used to improve the measurement estimates of the location of *below* ground theft on transit systems. Victims of theft offences on transit systems often have imprecise knowledge about *where* and *when* a theft occurred during their journey, they were not aware at the time an item was taken and only discover it sometime after the event. Options for estimating the location of a theft which could have occurred at or between several stations traversed during a transit journey include; using the start station, end station, a random station, or a midpoint station. On the London Underground (LU) the technique that has been traditionally used is the

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end station, known as End of Line (EOL) recording. However, analysis based on any of these measures will be deficient and based on skewed location data. A further option would be to omit these offences from crime analysis but for this study over 75% of theft offences on the LU were at unknown times and locations. Therefore this paper uses this ICA technique to better estimate the location of *below* ground theft, and compares these with *above* ground theft at known locations.

Scope

The scope of this research is restricted to one geographical area, the LU. This is a major *mass transit system* (also referred to as a public transport system), hereafter termed *transit system*, which carries in excess of 1,000 million passengers each year. The study is also focussed on a single crime classification, *theft from person*, hereafter termed *theft*. The theft offences considered in this study are usefully described as '*stealth-crimes*' by Smith (2008), an example of this is pocket-picking (also referred to as pick-pocketing) when an item is taken from a victim in one place, and not discovered missing until much later, normally somewhere else. This paper excludes *snatch-offences*, where a victim is aware at the time of the offence that their property is being taken, and other types of theft offences.

This paper does not attempt to compare theft offences on the LU with other transit systems. There are inherent problems due; to the diverse sizes of different transit systems; the mixed demographic and socio-economic conditions of areas they serve; the dissimilar times they operate; and variations in reporting and recording systems used (La Vigne, 1996). Indeed, as advocated by Smith and Clarke (2000) it is more pertinent to study transit crime patterns relative to the urban areas they serve rather than compare them to other regions. Therefore, this paper compares theft below ground with theft *above* ground in the vicinity of the LU transit stations.

In the financial year 2011/2012 the LU experienced 5,063 theft offences (British Transport Police, 2013), a rate of four thefts per million passenger journeys. These thefts constitute a large proportion (50%) of all crime recorded on the LU, a significant over-representation compared to the proportion of theft across the rest of the rail network in England and Wales (27%). These figures have remained fairly consistent over time (Clarke, 1984; Easteal and Wilson 1991; Burrell, 2007).

Research questions

The following questions were identified for this study:

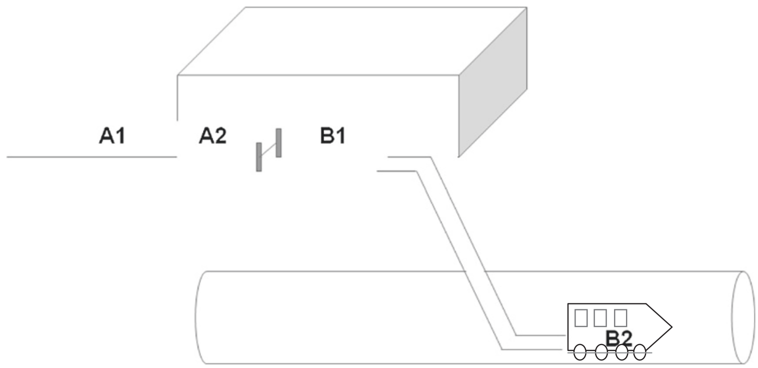
- What patterns of theft exist *below* ground on the LU?
- Is there a relationship between the distributions of theft *below* ground on the LU and theft *above* ground in the vicinity of LU stations?
- If a relationship does exist, how does this vary by location and time across different settings on the LU?
- Is there any evidence of a transmission of theft risk between *above* and *below* ground settings on the LU, and if so, what are the potential mechanisms for this?

Underground transit system settings

Underground transit systems contain four distinct environs presented in Figure 1 as Settings A1, A2, B1, and B2. For this paper it is contended these are all discrete types of public space. Setting A1 is *near* to but outside the boundary of a transit station; Setting A2 is inside a transit station but outside of control barriers which require payment to proceed through; Setting B1 is inside a station, within the paid area of a transit station, but outside of carriages, for example on a platform or stairwell, and; Setting B2 is inside an underground carriage. These four settings are present on systems which, by their very nature, are highly transient. A number of persons will enter, traverse, and leave transit systems over a relatively short space of time. Therefore, at each of these four settings there is a transient juxtaposition of potential offenders, potential victims of theft, and potential guardians against theft. Moreover, at each of these settings and over the course of the day, offenders' opportunities to commit theft, passengers' exposure to risk of theft, and the potential 'windows' available for supervisors and guardians to deter or apprehend offenders, will constantly change, fairly rapidly, within a small geographical setting.

This paper explores theft risk at each of these settings in order to gain a greater understanding of the mechanisms through which theft occurs on underground transit systems, and the degree to which there may be a transmission of theft risk between these settings. For the purposes of this paper, Settings A1 and A2 are considered to be *above* ground, and Settings B1 and B2 *below* ground. Those responsible for safety and enforcement, for example security managers and police enforcement agencies, have clearly demarcated jurisdictions and boundaries based on the *above* and *below* settings. On the LU for example, the Metropolitan Police Service (MPS) and City of London Police (CoLP) operate in Setting A1, and the British Transport Police (BTP) operate in Settings A2, B1 and B2, although there will be some 'spill-over' activity between the two.

Passengers use all four settings, for work, leisure, tourism, or other purposes. Their aim is usually to travel from departure to destination point, and generally as quickly as possible. For offenders however, movement is



A1: *Above* ground: Outside a station

A2; *Above* ground: Inside a station (before paid access control barrier)

B1: *Below* ground: Inside a station (after paid access control barrier)

B2: Below ground: Inside station (on carriage)

Figure 1 Potential theft settings at transit stations.

less well understood. They may use the transit system as part of their daily routine activities (Felson and Cohen, 1980), or be attracted to a particular setting because of the opportunities that it offers for theft (Brantingham and Brantingham, 1995). Different offenders may operate at each setting; or, offenders might travel through the entire system or selected parts of the system, and therefore operate at multiple settings.

'Formal' and 'informal' barriers exist between these four settings which may affect offender movement. There are few obstacles when travelling between Settings A1 and A2. To pass between Settings A2 and B1 requires a fare payment in order to move through a physical barrier. If an offender moves from setting B1 to B2, they have chosen to enter a rail car, which implies they have chosen to leave the station they are currently at and travel elsewhere, within new setting B2 until they choose to exit it. These 'barriers' may restrict movement between the four settings. Alternatively, movement to a different setting may result in reduced levels of supervision, increased targets, and better opportunities for theft, which might facilitate offender activity.

Mechanisms and settings: theft on underground transit systems

Whilst a number of studies have examined crime in and around transit systems (for good overviews see Smith and Clarke, 2000; Smith and Cornish, 2006; and Newton, 2014), few have explicitly explored this for theft. There are perhaps three key and inter-related issues evident in the literature, namely that; the presence of transit systems can influence and shape crime patterns in urban areas; transit stations may act as attractors and or generators of crime; and that transit stations serve as risky facilities.

Theft on transit systems

There is evidence to suggest that the presence of a transit system can influence and shape the crime patterns of urban areas (Piza and Kennedy, 2003). On transit systems a range of potential mechanisms can be identified for theft offences. Firstly, transit systems cluster people together at fixed locations in restricted spaces (Brantingham et al. 1991). Theft levels are greatest at transit stops and stations with higher passenger densities and this has been consistently found over a number of years (Smith and Clarke, 2000; Smith and Cornish, 2006, Newton, 2014). Indeed, Loukaitou-Sideris (1999) adapted Angel's 1968 idea of a critical zone of population density beyond which violent crime may occur, and suggested that on transit systems a second critical zone of intensity may exist. If reached, this critical point may be sufficiently high to mask and therefore promote less serious offences such as theft. Smith and Clarke (2000) suggest that while robbery and violent offences may be linked to a lack of supervision, theft may not be. This second level density may be applicable both the *above* and *below ground* settings of transit stations. High passenger densities may offer anonymity to offenders and a certain degree of jostling or bumping might be the norm (Loukaitou-Sideris et al. 2002).

Secondly, users of transit systems may be frequently exposed to situations whereby they are more susceptible to become targets for crime. The system congregates a number of different persons including 'demographically high-crime-risk people' such as teenagers, unattached males and those of low socio-economic status (Brantingham et al. 1991), and these users of the system constantly interchange (Richards and Hoel, 1980). Passengers may be unfamiliar with areas and more susceptible to victimisation (Block and Block, 2000; Piza and Kennedy, 2003). They may be easy targets, for example being tired, carrying accessible items, being pre-occupied, or distracted through travelling with young children (Myhre and Rosso, 1996). Again these may apply both *above* and *below* ground.

Thirdly, within transit systems passenger movement and space is restricted to confined settings. The fixed nature of transit stops (nodes) and routes (paths) restrict a passenger's choice of movement compared to other forms of transport, for example cars, bicycles or when on foot. Indeed, passengers have minimal control over where and when they enter and exit a system, where a carriage stops, and, once inside a carriage, it is difficult to exit if someone 'suspicious' boards. On underground systems passengers typically travel on only a few of the available routes, and do not become familiar with areas they traverse as they travel below the ground. On the other hand stations offer easy and rapid entry and exit points for offenders (Block and Block, 2000; Loukaitou-Sideris et al. 2002), and they can linger at stations for long time periods without arousing suspicion (Block and Davis, 1996; Piza and Kennedy, 2003). Therefore, transit systems are likely to be highly attractive to offenders. As an offender traverses a transit system, particularly in areas adjacent to their daily routines and paths (termed routine activities by Felson and Cohen, 1980), they can increase their awareness of potential crime opportunities. A passenger's knowledge of vulnerability is only likely to change if they experience an offence, and, even if they became a victim of theft, they may not know exactly where and when this happened, thus cannot readily identify where elevated levels of risk are. Anecdotally, it is possible regular commuter trips, and increasing use of social media and mobile technology such as smart phones, could result in greater communication between passengers about levels of theft risk on transit journeys. However, the latter may also increase possible targets for offenders and assist in communication between offenders.

Transit stations and hubs have been identified in the research literature as potential crime attractors and crime generators (Smith and Clarke, 2000). Crime attractors draw offenders to them, they are locations with known opportunities for crime. Crime generators are subtly different, as the presence of a large number of people (offenders and victims) brought together at the same time and place can generate unplanned but often favourable crime opportunities (Brantingham and Brantingham, 1995). On public transit both are possible (Smith and Clarke, 2000; Burrell, 2007, Newton, 2014), and the main distinction tends to be time of day and type of offence. Low level sexual assaults and thefts tend to occur in crowded situations during peak travel times (a possible crime attractor) whereas violent crimes are more likely to occur in more isolated settings with lower passenger densities (a potential crime generator).

Transit stations have also been acknowledged as a good example of 'risky facilities' (Clarke and Eck 2005, Felson and Boba, 2010) as the majority of crimes that occur at transit stations are concentrated at a small proportion of stations; the so called 80/20 rule. This has been found in a number of studies of transit stops and stations (Loukaitou-Sideris 1999, Pearlstein and Wachs 1982; Newton and Bowers, 2007). Theft is concentrated at crowded stations at peak travel times, during the early morning and late afternoon rush hours (Burrows, 1980; Pearlstein and Wachs, 1982; Kabundi and Normandeau 1987; Loukaitou-Sideris, 1999; Cozens et al. 2003; Burrell, 2007). Research by Clarke et al. (1996) found bag opening peaked between 0800 and 1000 hours, and between 1600 to 1900 hours; the morning and afternoon peaks for passenger travel. Levine et al. (1986) identified that crowding was a feature at two bus stops they observed with high theft levels. Additionally, Ceccato et al. (2011) found theft rates at stations were higher during the warmer months of the summer, and in larger stations with more platforms.

It is less clear whether more transit crime occurs at stops and stations, or on board carriages. Some studies suggest more transit crime occurs at stations (DeGeneste and Sullivan 1994; Loukaitou-Sideris 1999 and Loukaitou-Sideris et al. 2002) and that the presence of drivers on carriages deters offenders. One study in the US found that 50% of transit larcenies occurred on trains (Smith and Clarke, 2000). For this study more than 75% of theft was at an unknown location, and could have occurred on carriages or at stations, which makes it difficult to compare risk between these two settings on the LU.

The potential transmission of crime risk between transit settings

The majority of studies on transit theft focus on known offences at busy stations at peak times, in other words *above* ground theft. One of the few studies to compare crime offences *inside* a station with those *outside* a station (La Vigne, 1996) found that levels of robbery and Part 1 crimes within a station including larceny, thefts, and pocket-picking, did not correlate with high levels of these offences outside of stations. However, the analysis of assaults did find a correlation between the *inside* and *outside* environments. It is not clear what this relationship was for pocket-picking as this offence type was aggregated into the larger category of Part I crimes. The low crime rates of the Washington D.C. transit system were attributed to its design. It is difficult however to identify why these design features did not insulate against assaults. A potential explanation provided by the author was that assaults are more likely to be committed by persons living close to stations. However, very few studies have actually examined offenders' use of transit systems. Belanger (1997) suggested more offenders will travel within their own borough to commit crime, and Smith and Clarke (2000) suggest offenders tend to use transit systems to commit crime in central business districts but rarely to reach suburban areas beyond their own localities.

There is some evidence of elevated crime risk around transit systems, what Block and Block (2000) term the environs of rapid transit. However, this is multifaceted and complex. Bernasco and Block (2011) found that whilst stations serve to increase the accessibility of an area, their presence alone is not sufficient to increase crime risk. Furthermore, the introduction of a new station does not necessarily equate to an increased crime rate in that area (La Vigne, 1996; Sedelmaier, 2003). Moreover, if a minority of stations account for a large proportion of crime (risky facilities) this then implies that several stations actually experience few crime incidents (Vu, 2009). It is argued therefore that there is a poorly understood interaction occurring between transit systems and their wider environment, termed spatial interplay by Robinson and Goridano (2011) The notion of a spatial interplay and transmission of theft risk around transit stations are key notions explored in this paper.

Bowers (2013) used a spatial regression model to examine the relationship between internal theft, inside risky facilities, and external theft, outside a facility. A number of types of risky facilities were examined, although underground stations were not included. The paper also considered all personal thefts including snatching and other theft. An interesting concept proposed was that risky facilities may act as 'radiators', as internal crime is transferred to external environments, or as 'absorbers', as risky facilities absorb crime from nearby high crime areas. Bowers finds evidence that "*internal theft problems precede external ones and that the physical concentration of chronically risky facilities is a particularly strong predictor of external theft problems*" and that *"risky facilities act as crime 'radiators', causing crime in the immediate environment as well as internally" (pp unknown, advance access)*. This supports the notion that there is a possible relationship between internal and external crime at risky facilities. This paper explores this specifically for underground train stations.

The risky facilities examined in the Bowers study only consider theft at *above* ground settings (A1 and A2 in Figure 1). Stations are perhaps a unique type of risk facility for several reasons: they are connected by the *below* ground setting (B2); there is a paid access barrier between the internal and external setting (A2 to B1); and, entrance to and exit from a risky facility may be through the entrance to that risky facility, or it actually may be entered or exited from *below* ground, in other words using a nearby station.

This paper explores the possible transmission of risk of pocket-picking offences between the *above* and *below* settings of underground rail systems. The risk that mass transit engenders is known not be uniform across the system, yet the manifestation of theft inside transit systems, *below* ground, is not well understood, due to current measurement deficiencies in the recorded crime data. This paper therefore will address this through the use of *ICA*.

Data and methodology

This section of the paper discusses the data used in the study and the methodologies employed.

Data

This study uses data on theft offences captured both *above* and *below* ground. For setting A1, offences were extracted as recorded by the MPS and CoLP between 1st April 2011 and 31st March 2012, using the following Home Office (HO) classifications; shoplifting (HO classification 46); theft person (HO classification 39); and theft other (HO Classification 49). Records were extracted that occurred within 100, 250 and 400 metre buffers of LU stations. A discussion of using this buffer method for capturing theft offences 'around' stations is provided later. For settings A2, B1 and B2 offences were extracted as recorded by BTP between 1st April 2011 and 31st March 2012, and the following codes were captured; theft luggage (J02), theft personal property (J03), theft from the person (J04) and shoplifting (J22). For setting A2, only those offences with known locations, in other words those known to have occurred at LU stations were included. For settings B1 and B2, offences captured by BTP that occurred as part of a transit journey at unknown locations were used to inform the ICA analysis.

Interstitial crime analysis

The Interstitial Crime Analysis (ICA) measure is calculated using the following procedure. Using extracted codes J02, J03 and J04, offences were categorised by those that occurred *above* and *below* ground based on the station location code. The ticket boundary was used to define the transition from the unpaid (A2) to paid (B1 and B2) environments. A small proportion of records were excluded as they could not be categorised into A1, or B1 and B2. A probabilistic modelling technique was used (Gill, 2007) to calculate ICA values. This is based on a similar technique to Aoristic Crime Analysis which was developed by Ratcliffe (2002) to better estimate the times of burglaries between two time periods, from exiting a house, to discovering a burglary. Ashby and Bowers (2013) compared this technique with alternative methods for estimating temporal uncertainty in crimes, and found aoristic crime analysis to be the most accurate. The ICA method is used to better estimate the locations of underground thefts between a start and end station.

Take theft 1, which is a hypothetical example in Figure 2. If a theft victim starts their journey on the Victoria Line at King's Cross St. Pancras station, and discovers their purse missing at Oxford Circus station, then, their journey involves a start station (King's Cross St. Pancras), three intervening line segments, and an end station (Oxford Circus). Interpolating the risk of theft between these five settings, namely, two stations and three segments, generates a probability value of 0.2 at each of the five possible settings along the victim's journey. However, a further possibility is Theft 2 (Figure 2), where a passenger starts at Kings Cross, changes at Euston, and discovers the theft at Warren Street. Here there are again five possible locations of theft, three stations, including one interchange, and two segments. This methodology was repeated for all journeys on the network to give a cumulative probability risk for each station and each route segment (Figure 2). This analysis assumes there is an equal likelihood of theft at a station or interchange or on a carriage between stations. Potential limitations of this will be discussed later.

For each station, an ICA score was generated using below ground thefts (settings B1 and B2; N = 4,237). This was calculated for 249 valid LU stations. One station was excluded as it was closed during the time period under consideration. London Docklands Light Railway (DLR) stations were also excluded due to missing information. The cumulative probability measure described in Figure 2 provide a minimum of three cumulative probability scores at each station; two route segments, one to the station, and one from the station, as route segments operate in two directions; and the individual station value. To calculate the ICA risk score for each individual station, the cumulative probability values for each station, plus the total number of contiguous route segments (to each station or from each station segment) were added together, and this was then divided by the number of lines each station serves, as stations can serve multiple lines, to produce an average ICA value for each station. In addition to the ICA score for each station, an adjusted ICA score was calculated, the ICA value standardised per million passenger journeys at that station (ICA adj*).

The ICA also allows analysis to be bounded by user specified times of the day. A restriction is that passenger journeys are available on an hourly basis, so the ICA adj* measure can as a minimum estimate theft risk per passenger per hour, as will be demonstrated later in this paper. However, different time periods can be selected and theft risk within these cross-sectional time periods can be examined, for example for a full 24 hour time period, or for peak and off peak travel times.

This measurement estimation has been termed Interstitial Crime Analysis for the following reasons. An interstice is defined as *an intervening space, especially a very small one,* originating from the Latin *interstitium*, which derives from *intersistere*, to *'stand between'* (Oxford English Dictionary ND). Interstices were originally used in the Chicago school by Burgess in his 1925 concentric model of residential zones as an alternative name for the concentric zone of transition, termed the *interstitial* area. The use of the interstitial spaces of crime can be identified in the literature on crime, for example Felson (2006) who describes these as *in-between* areas near to where people go for legitimate activity. On transit systems Felson et al. (1996) identify interstitial areas at the Port Authority Terminal. Whilst not all settings on transit systems can be considered truly interstitial, it is proposed here that this term is appropraite to describe this method of crime measurement. It refers to a method that estimates crime locations between places, and, it is based on settings where there is constant transition, the movement of both people and rail carriages.

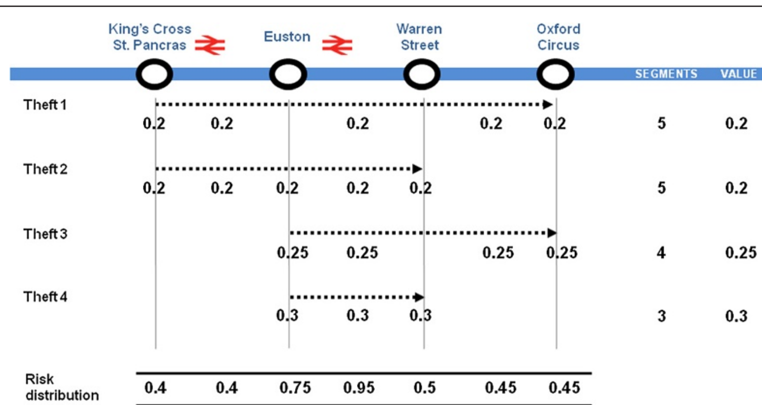


Figure 2 Calculating the ICA: hypothetical example.

Examining theft above and below transit systems

For this research, four values of below ground theft (setting B1 + B2) were calculated. The need to distinguish between crime counts (number of offences) and crime rates (offences per person at risk) is well established, for example burglary per 1000 dwellings or robbery per 10,000 persons. Ceccato et al. (2011) demonstrated how passenger journeys can be highly influential to crime risk on transit journeys. For this paper annual passenger journeys per million passengers were used as a suitable denominator, and four possible measures of below ground theft were calculated for each LU station using both the new ICA measure and the traditional EOL measure and these were:

- EOL, non-standardised counts of theft using the EOL measure;
- ICA, non-standardised counts of theft using the ICA measure;
- EOL adj*, theft rates standardised per million passenger journeys using the EOL measure; and;
- ICA adj*, theft rates standardised per million passenger journeys using the ICA measure.

In order to answer the posed research questions the following methods were adopted; firstly, a Lorenz Curve was used to test whether stations exhibited characteristics of risky facilities, a large proportion of theft should occur at only a few stations; secondly, estimates of the locations of below ground theft risk were visualised using proportional circles in a Geographical Information System (GIS) to examine their spatial distribution; and thirdly, to test the relationship between *below* and *above* ground theft, Spearman's Rank correlation analysis was used to compare theft *above* ground in settings A1 and A2, with theft *below* ground in settings B1 and B2 combined (B1 + B2). The results of this analysis are now described in detail.

Results and discussion

This section presents the main findings of this research and a discussion of the results.

The distribution of below ground theft

The literature suggests stations will act as risky facilities for theft and will exhibit the 80/20 rule; that most theft occurs at a small proportion of stations. In order to examine this, Lorenz Curves were produced (Figure 3). For theft at known locations *above* ground, setting A2 in Figure 1, this relationship is evident; approximately 80% of theft happens at about 20% of stations. Figure 3 also includes Lorenz Curves for estimated *below* ground theft risk, the ICA and ICA adj* scores. Although the concentrations evident for these two estimates are not as strong as the theft *above* ground, both *below* ground measures still estimate a large proportion of theft at a small proportion of stations. For the ICA adj* scores it is estimated that 50% of theft occurs at 20% of stations, and 75% of risk occurs at 40% of stations. Whilst this is not strictly an 80/20 result, this is not an exact science. Furthermore the measure is actually likely to underestimate the risk at stations with highest theft levels, and overestimate this at low risk stations. This is because in the construction of ICA scores, for every transit journey that experienced a theft, all stations and route segments that journey are assigned an equal probability of risk. The EOL produced a similar curve to the ICA, and the EOL adj* produced a similar result to the ICA adj*, therefore both techniques here demonstrate evidence of risky facilities; below ground theft is concentrated at a small proportion of stations.

The locations of *below* ground theft estimated using the *ICA* and *ICA adj** measure were mapped using a GIS. They are shown as proportional circles for ICA (Figure 4) and ICA adj* (Figure 5); stations with higher scores are represented by larger circles. In Figure 4, theft offences tend to be pulled towards the centre of the transit network, which represents stations with higher passenger numbers. In Figure 5, adjusted for passenger journeys, the ICA adj* score is dispersed more spatially, through the network. It is no longer pulled towards the centre of the network, yet concentrations are still evident at particular stations, the most risky facilities. A visual comparison with the EOL measure showed that this estimate skewed thefts towards stations at the end of lines, and, when standardised by passenger journeys, the EOL adj* did not alter substantially. This suggests visually that the ICA adj* is a superior method to the EOL adj* for estimating below ground theft and this method will be used for further analysis in this paper, although EOL adj* comparisons will be drawn where appropriate.

Theft above ground: *at* and *near* to stations

The next stage of this research was to test the relationship between *above* ground theft *near* transit stations (Setting A1) and *above* ground theft *at* transit stations (Setting A2), and the results of this analysis are provided in Table 1. This shows that stations with high counts of theft from person tend to have high levels of theft in their surrounding environs (shoplifting; other thefts; and theft from person). When standardised by passenger journeys, it is evident that only theft from person offences are significantly correlated between settings A1 and A2 (rho = .219, N = 249, p = 0.00). Thus, there is evidence of a relationship between theft from person rates (pocket-picking) inside stations and *near* stations, but this is not evident for shoplifting and other theft once standardised as rates per million passenger journey.

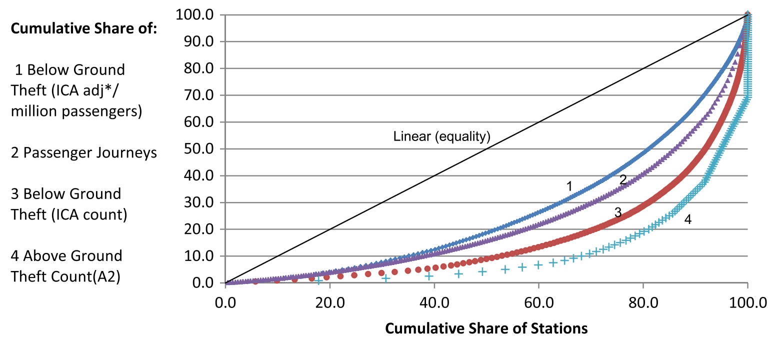


Figure 3 **Lorenz Curve: inequality in shares of theft per station.**

Shoplifting *at* stations is negatively correlated with all categories of theft *near* stations, although correlations are low and only significant at the 95% confidence level.

Theft above and below ground

Three distinct settings were examined, A1 and A2 *above* ground, and B1 and B2 *below* ground. Currently the ICA method cannot distinguish between settings B1 and B2, thus *below* ground settings where the location of theft is unknown are depicted as a combined value (B1+2). The relationship between thefts at these settings was examined using the Spearman's Rank correlation tests for association. Results are presented in Table 2. The ICA adj* score for theft from person *below* ground was positively and significantly correlated with *above* ground theft for; theft from person *near* stations in Setting A1 (rho = 0.228, N = 249,p = 0.00); and theft from person *at* stations in Setting A2 (rho = 0.280, N = 249, p = 0.01). This was also negatively and significantly correlated with shoplifting *at* stations in Setting A2 (rho = −0.277, N = 249, p = 0.00). Other theft types did not show significant associations. Theft *below* ground estimated using the EOL adj* method was not significantly correlated with theft *above* ground.

Theft above and below ground by time of day

Previous research has demonstrated that theft is most prominent at peak travel times during the rush hour. Therefore as an extension to the previous analysis, theft *above* and *below* ground were compared by across different times of the day periods. These were constructed based on passenger usage models of the LU recommended by Transport for London (TfL), and also a visual

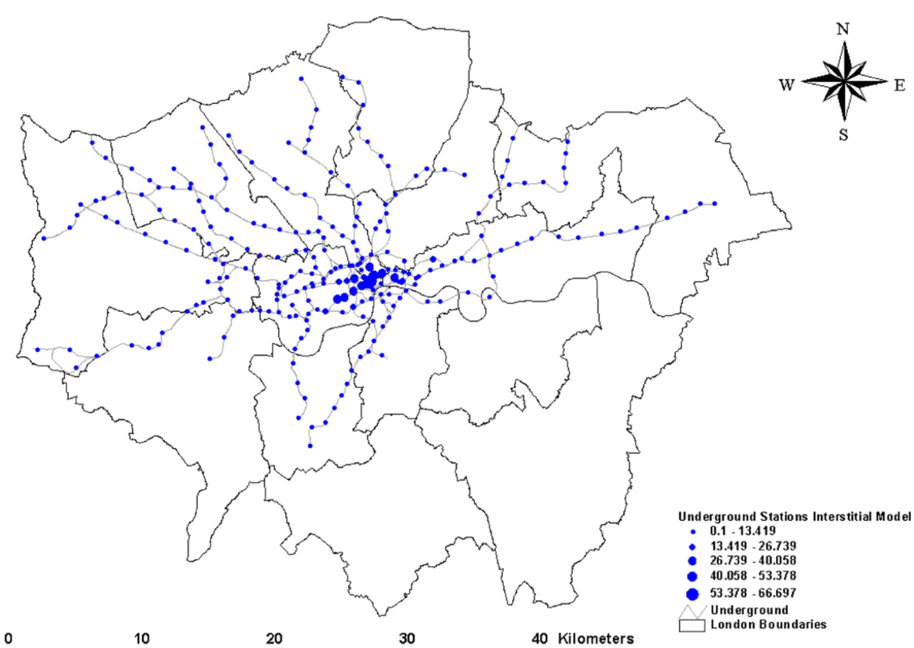


Figure 4 **Theft risk *below* ground in transit stations: risk estimated using the ICA measure.**

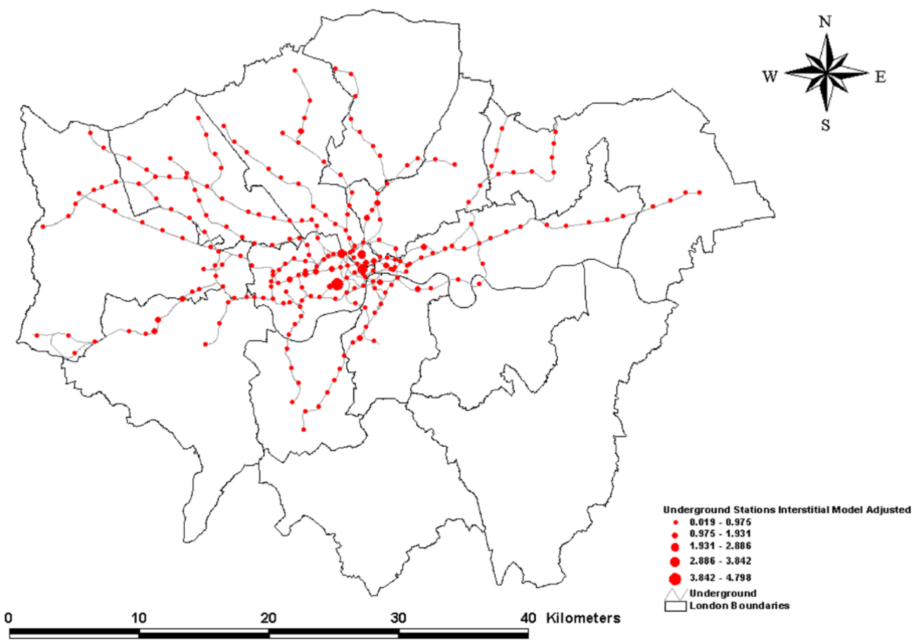


Figure 5 Theft risk below ground in transit stations: risk estimated using the ICA adjusted measure.

inspection of the theft counts and rates by hour of day. The classifications used were: early (02.00-06:59); am peak (07.00-09:59); inter-peak (10.00-15:59); pm peak (16.00-18:59); evening (19.00-21:59); and late (22.00-01:59). Theft offences were subdivided into these six categories and standardised by passenger counts for the equivalent time periods. A further consideration here is the time categories used are not equal in terms of the total number of hours available, some have a larger time window within which theft could be committed. Therefore, theft was further standardised, by passenger numbers per million journeys, and per available hour of risk, and the results are presented in Figure 6. This shows as expected the morning and afternoon peak travel times have the highest rates of theft per passenger per hour, and thus these time categories were considered appropriate for this analysis.

For each of the six time periods, theft *above* ground (A1) was compared with theft below ground (B1+2) using Spearman's Rank correlations tests and the results of this are presented in Table 3. This shows the theft

Table 1 Correlation between theft *at* stations and theft *near* stations (250 m buffer), London Underground, 1st April 2011 to 31st March 2012

Spearman's correlations (rho)				
Crime counts		**A1: *Near* stations**		
		Shoplifting	**Other thefts**	**Theft from person**
At Station (A2)	Shoplifting	−0.09	0.03	0.07
	Theft of personal property	0.06	*.158	0.11
	Theft from person	****.284**	****.490**	****.502**
Crime rates (per million passenger journeys)		**A1: *Near* stations**		
		Shoplifting	**Other thefts**	**Theft from person**
At Station (A2)	Shoplifting	*-.158	*-.192	*-.159
	Theft of personal property	−0.08	−0.11	*-.201
	Theft from person	0.07	0.03	****0.219**

**Correlation is significant at the 0.01 level;
*Correlation is significant at the 0.05 level.

Table 2 Correlation between theft *near* stations (250 m buffer), theft *at* stations, and theft *below* ground on the London Underground, 1st April 2011 to 31st March 2012

Spearman's correlations (rho)				
Theft from person (per million passenger journeys)		**A1: *Near* stations**		
		Shoplifting	**Other thefts**	**Theft from person**
Below ground theft (B12)	End of Line	−0.09	*.141	0.108
	Interstitial Crime Analysis	*-.132	*.135	****.228**
Theft from person (per million passenger journeys)		**A2: *At* stations**		
		Shoplifting	**Theft property**	**Theft from person**
Below ground theft (B12)	End of Line	*-.180	0.044	.045
	Interstitial Crime Analysis	****-.277**	−0.115	****.280**

**Correlation is significant at the 0.01 level;
*Correlation is significant at the 0.05 level.

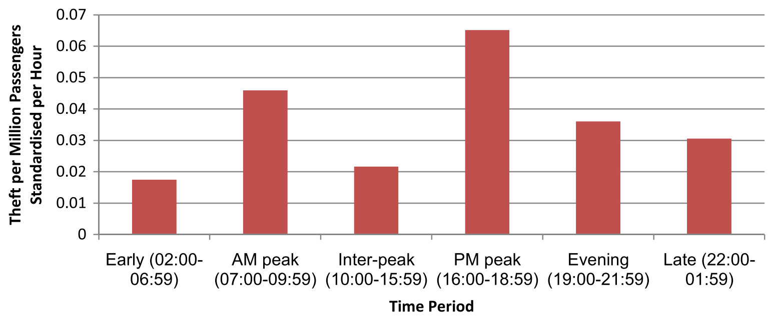


Figure 6 Theft on the London Underground by time of day (standardised by passenger volumes and available hours in each time period).

below ground (B1+2) estimated using ICA adj* is significantly and positively correlated with theft *above* ground (A1) during the am peak (rho = .169, N = 249, p = 0.00) and the pm peak travel times (rho = .261, N = 249, p = 0.00). It also identifies significant correlations for early morning (rho = .425, N = 249, p = 0.00) and evening time periods (rho = .190, N = 249, p = 0.001). However, and this was perhaps not expected, correlations were not found with theft *above* ground during the inter-peak and late night time periods. A comparison with the EOL adj* method found no significant correlations between *above* and *below* ground theft for any of the six time periods examined.

Discussion of findings

The results of this analysis support the current literature, and suggest that theft from person on the LU is concentrated at particular stations and particular times of the day. Stations exhibit expected characteristics of risky facilities, a large proportion of thefts occur at a small proportion of stations (the 80/20 rule). This is evident both *above* ground (A2) and *below* ground (B1 + B2), and holds true when examining both theft counts, and theft rates standardised by per million passenger journeys.

Table 3 Correlation between theft *near* stations (250 m buffer) and theft *below* ground on the London Underground by time of day, 1st April 2011 to 31st March 2012

Spearman's correlations (rho)				
Theft from person (per million passenger journeys per hour)		A1: *Near* stations		
		Shoplifting	Other thefts	Theft from person
Interstitial Crime Analysis: *Below* ground theft (B1+2)	Early (02–06:59)	0.087	****.375**	****.425**
	Am peak (07–09:59)	−0.05	****.173**	****.169**
	Inter-peak (10–15:59)	−0.083	0.025	0.105
	Pm peak (16–18:59)	*-.129	*.127	****.261**
	Evening (19–21:59)	−0.06	0.084	****.190**
	Late (22–01:59)	*-.132	0.012	0.026

**Correlation is significant at the 0.01 level;
*Correlation is significant at the 0.05 level.

The ICA analysis also suggests that theft on underground systems is highly transient, and the risk is not uniform across the system and changes spatially by time of day. The analysis also suggests that the ICA adj* method is more appropriate for examining theft risk on the underground than the EOL measure.

This paper also contends that there is a transmission of theft risk between the *above* ground and *below* ground settings. A comparison of theft *near* stations (A1) and *at* stations (A2), both *above* ground shows a positive significant correlation for theft from person; this relationship is not evident for other theft types. Moreover, when comparing theft *above* ground (settings A1 and A2) with theft *below* ground (settings B1 + B2), it was evident that stations with a high risk of theft *below* ground are located in areas with high levels of theft *above* ground, and this applies both *at* stations (A2) and *near* stations (A1). Again this applies to theft from person and not other theft types. Upon further examination, it was found that the significant positive correlations evident between the *above* ground settings *near* stations (A1) and the *below* ground (B1 + B2) settings inside the LU, were only apparent at certain times of the day, and that the strongest relationships were evident during the peak travel times. During the inter-peak and late night times, theft *above* and *below* ground were not correlated. This suggests that there is a transmission of theft risk between the *above* and *below* ground settings of the LU, which is especially evident during peak travel times, and specifically for theft from person and not other types of theft offences. Indeed, there were some negative relationships found between shoplifting and theft from person.

There are a number of potential explanations for this identified likely transmission of theft risk: those factors conducive to theft *below* ground and *above* ground are similar, but different offenders operate at each setting; that the same offenders operate *below* ground and *above* ground; or that an alternative explanation exists. It is contended here that that the same offenders operate between these different settings and that the transition between each setting, including access though paid barrier controls (A2 to B1) is not a major obstacle to movement. The introduction of anonymous travel cards on the LU including; pre paid Oyster cards, a top up pay as you go plastic smartcard for travel that does not need to be registered to individuals and can be bought using cash; and all day travel cards that can be bought with cash; may have reduced the deterrent effect of paid access control, especially for theft, as offenders are able to travel all day undetected and unrestricted for relatively cheap amounts, compared to the potential rewards gained.

Further to this, it is suggested stations with good opportunities for theft both *above* ground (A1 and A2) and *below* ground (B1 and B2), have the highest levels of theft risk, and that this risk is greatest at peak travel times. Outside of peak travel times it is possible offenders seek alternative stations or settings outside of transit environments, as there are fewer passengers, therefore less targets and less anonymity, and detection may be more likely. Indeed, the juxtaposition of favourable conditions for theft *above* and *below* ground at peak times may not be present at off peak times. At night-time the favourable theft settings for *above* ground theft may be influenced by the location of establishments that serve alcohol, and thus these may be very different to those during the peak travel times, and the optimal conditions for theft *above* and *below* ground experienced at peak travel times may not correspond with this night-time period.

It is also suggested that offenders who commit theft from person offences *near* and *inside* transit systems are perhaps specialised, as relationships were not found between areas with high levels of theft from person and other theft types. Indeed some negative correlations were found between theft from person and shoplifting. The most likely explanation here is offenders who commit shoplifting are different to those who commit theft from person offences, due to the different skills sets required.

Limitations

This study used recorded crime data provided by three organisations, BTP, the MPS, and the CoLP. A limit of using recorded crime data is that it will under-estimate actual levels of crime. On transit systems the extent to which this occurs is unknown, although Levine and Wachs (1986) suggest actual levels of crime on transit systems may be 20–30 times that of reported levels, a possible limitation of the BTP data. Levels of theft outside transit systems are also known to be under-reported, and it is estimated only 29% of thefts in England and Wales are reported (Chaplin et al. 2011) which may be a limitation of the MPS and CoLP data. However, this analysis compares theft across different settings *inside* and *near* transit stations. There are no obvious reasons why theft at or *near* one station will be better reported than that of another station in London. Therefore, it is not thought the under-reporting will bias the correlation analyses carried out in this study.

The buffer zone selected for crime *near* stations (Setting A1) was theft within 250 metres of a station. This could be criticised as the size of the buffer used for theft *near* stations may impact on the sensitivity of the correlations observed. The analysis in sections 4.2 and 4.3 was repeated using 100 m and 400 m buffers to see if any discernible differences were observed. Similar correlations were found using all three buffers. Therefore, it is suggested the 250 metre buffer zone chosen is an appropriate buffer for Setting A1, theft *near* a station.

A limitation of the ICA method is that it assigns an equal risk to all settings *below* ground, thus a station and a route segment are assigned the same probabilities of theft. During a passenger journey, each route segment, each start and end station, and each interchange, are all given an equal weight. This equality of risk could be criticised, for example; are platforms more risky, is entering a carriage more risky, or is being on a carriage more risky? Due to the transient nature of these settings this risk may constantly vary. Unfortunately it is not possible at present to distinguish between theft in setting B1 and setting B2, and detection rates for theft on the LU are low (4%, BTP, 2013). Furthermore, a range of factors could influence risk and these include; the average journey time between each interstice; the average waiting time at each platform; the number of carriages on a train; the length of each platform, and whether more passengers wait at the front, middle or rear of the platform, which may be a result of where the entrance and exits to each platform are situated. At present settings B1 and B2 have been assigned equal values of risk in the construction of the ICA score although future work could seek to refine this modelling procedure.

Conclusions and future research

This paper has introduced a new technique termed ICA, in order to better identify the location of underground theft on mass transit systems. Through this innovative methodology, the paper has explored the distribution of theft *below* ground on the LU, and, also, the relationship of this to *above* ground theft, both at stations and in their immediate vicinity. The ICA measure was compared with the EOL technique for estimating the location of below ground theft. The findings suggest the ICA measure more appropriate than the EOL, and that the ICA adj* rate (standardised per million passenger journeys) is an appropriate measure of identifying theft risk *below* ground on the LU.

The findings are consistent with the research literature; stations act as risky facilities and most theft is concentrated at a small proportion of stations and during peak travel hours. This research extends the current evidence base however, as it is also able to estimate risk of theft below ground on the LU. It finds that both the *below* and *above* ground settings exhibit characteristics of risky facilities, especially at peak travel times. Moreover, stations with high levels of theft tend to have environs (settings adjacent to the station) with similarly high levels of theft. Findings of some previous studies, that good design can insulate stations from external conditions are not replicated in this study. Indeed a likely transmission of theft risk is observed, between the *above* and *below* ground settings of LU stations.

It is contended from this that there are three possible mechanisms of theft that emanate on transit systems and their nearby environs. These are:

- the presence of 'uni-nodal' offenders – who operate at only one station or a limited number of proximate stations;
- the presence of 'multi-nodal' offenders – who operate between multiple terminals;
- system causes of theft – driven by the juxtaposition of busy stations and favourable opportunities for theft created by the presence of transit settings;
- other causes of theft.

Whilst these may not be mutually exclusive, the evidence presented in this paper suggests the second and third options are more probable. Further research should explore these hypotheses in more detail.

Policy implications

The findings of this research highlight particular areas for future policy development for preventing theft, both *inside* and *near to* transit stations. The first of these is that the research suggests offenders do not distinguish between *below* and *above* ground targets, and that BTP, CoLP and the MPS should consider more joined up operations to target offenders who commit theft. Even if the actual offenders are different, the high risk locations of theft *above and below* ground tend to be similar especially at peak travel times. However the research finds no evidence that those who commit thefts will only specialise on transit networks, or only outside of transit networks. A transmission of risk between the *above* and *below* ground environs is more likely. It could be hypothesised that offenders act in the knowledge that information is not well shared between the different enforcement agencies, and move regularly between the above and below settings discussed in this paper, to avoid detection and suspicion. Additionally, it is evident that theft on the underground is dynamic and mobile and prevention activities should thus be designed and implemented accordingly, for both short term detection and longer term prevention. The adoption of the ICA model by BTP should enable further improvements over time, as the more the model is used, and the more data is included in this model, the more it is likely to iteratively improve in its estimation of the location of the below ground theft. Further refinement could include weightings for risk of theft *below* ground, on carriages and inside stations (settings B1 and B2).

Future avenues for research

A clear finding from this analysis is theft offences on the LU are not uniform but are highly transient in both space and time. There is some evidence of a spatial interplay in the environs of transit stations (between *above* and below), but this is still poorly understood. A closer examination of features present in settings A1, A2, B1, B2 and their influence on theft may help to better understand risk and influence future prevention techniques. These could include for example; the internal design of a station and features such as the presence of cash points (ATMs), lighting, CCTV and lines of sight. There are also features around stations that influence theft opportunities such as the presence or absence of different land features, for example shops, residential dwellings, and bus stops. A future research avenue should be to examine the spatial interplay of these features, their influence on theft, and furthermore how this may vary at different times of the day, for example peak versus non peak travel times.

Further research is needed into the extent to which offenders may use transit systems to facilitate their movement and activities. A hypothesis that could be tested is whether offenders who commit theft on transit systems operate using crime scripts, similar to the master crime scripts used by burglars. Upon entering a property a burglar will often first visit the master bedroom, then a main living room, and so forth. The hypothesis here is that an offender will first visit their preferred location for offending, station A. If they do not find suitable conditions to offend, they may then move to station B, and this movement may be via the underground. They may identify opportunities to offend whilst travelling on the underground between station A and B. If an offender does not find a suitable theft opportunity they may then move to station C, their third preference, and so forth, or even back to station A. A research avenue here would be to identify what characteristics make station A more attractive to offenders, both above and below ground, and to ascertain how this might vary by time of day and day of week. Whilst offender interviews would be one potential mechanism for exploring this, site visits at high and low risk stations may also uncover some of these influences on theft.

A final area for further research is to examine the type of items stolen by offenders. Whilst crime in England and Wales has been reducing for a number of years (Chaplin et al. 2011), this reduction has not been observed for theft person. Some anecdotal reports suggest theft of mobile phones may be a driving force behind this. Therefore an important analysis would be to examine the items stolen in theft from person offences on transit stations, similar to the CRAVED principles (Clarke and Eck 2005) used in other studies. On transit systems this should also be examined by location and time of day.

Abbreviations

BTP: British Transport Police; CoLP: City of London police force; DLR: Docklands light railway; EOL: End of line; GIS: Geographical information system; ICA: Interstitial Crime Analysis; MPS: Metropolitan police service; LU: London Underground; TfL: Transport for London.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AN is primary author and was responsible for the bulk of the writing and the analysis used in this paper. HP is the second author on this paper. He was responsible for arranging access to and preparing the data used in the study and in drafting some of the sections for this paper including the construction of ICA scores, and commented on several versions of this paper. AG commented on various drafts of this paper, and was central to the development of the ICA measure. All three authors were responsible for the design of this study, and read and approved the final manuscript.

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