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**Rummage Search by Expert Dyads, Novice Dyads and Novice Individuals for Objects Hidden in Houses**

Charlotte A. Riggs1, Hayward J. Godwin1, Carl M. Mann1, Sarah J. Smith2, Michael Boardman2, Simon P. Liversedge1 and Nick Donnelly1

1University of Southampton, UK

2Defence Science and Technology Laboratory

Charlotte A. Riggs, School of Psychology, University of Southampton; Hayward J. Godwin,School of Psychology, University of Southampton; Carl M. Mann,School of Psychology, University of Southampton; Sarah J. Smith, Human and Social Sciences Group, Defence Science and Technology Laboratory; Michael Boardman, Human Factors Integration Team, Defence Science and Technology Laboratory; Simon P. Liversedge, School of Psychology, University of Southampton and Nick Donnelly, School of Psychology, University of Southampton.

Carl M. Mann is no longer affiliated with the University of Southampton.

Correspondence concerning this article should be addressed to Charlotte A. Riggs, School of Psychology, University of Southampton, Highfield, Southampton, Hampshire, SO17 1BJ. Tel: +44(0)2380 595078; Email: C.A.Riggs@soton.ac.uk.

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Disclosure of Interest

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**Abstract**

Rummage search is the visual and haptic search of complex environments for targets. In this study, rummage search was explored using a novel analytic framework with expert dyads and novice dyads, as well as novice individuals. Participants sought an unknown number of targets placed in four rooms of a residential house. Some targets were plainly visible whereas others were hidden, and could only be found through haptic examination. Expert dyads were very good at the task, conducting a slowed, double-checking exhaustive search, while novices both failed to fixate potential target locations, and failed to carry out the appropriate action required to search those locations exhaustively. The novice dyads examined more than the novice individuals, but became more superficial in their search. We conclude that effective rummage searching is a skill enhanced by training.

*Keywords:* rummage search, visual search, eye movements, teamwork, expertise.

**Rummage Search by Expert Dyads, Novice Dyads and Novice Individuals for Objects Hidden in Houses**

Rummage search (RS) is a form of real-world visual search where searchers engage in the visual and haptic search for targets. RS often requires searching over large areas such as a queue of vehicles, a number of houses or big public venues. Targets in RS may be visible and in plain sight, or they may be hidden from sight underneath or inside other objects such that some motoric action is required to find them. We engage in forms of RS in everyday life, for example when looking for our keys in a coat pocket or a mobile phone on a messy desk. However, when in security critical scenarios, RS is often conducted to find items that are purposely hidden. The police, military and border agencies perform RS to find weapons, drugs and Improvised Explosive Devices (IEDs). Despite being a skill that is trained, there have been relatively few studies exploring aspects of RS (Foulsham, Chapman, Nasiopoulos, & Kingstone, 2014; Gilchrist, North, & Hood, 2001; Jiang, Won, Swallow, & Mussack, 2014; Smith, Hood, & Gilchrist, 2008). These studies do not provide much of an evidence-base for either understanding RS or improving its training. The primary goals of the present study are to present a framework for studying RS and to then use this framework to establish a clearer evidence base for determining how the training of novice rummage searchers might be enhanced.

Laboratory experiments on visual search are a starting point in providing some insight into RS. There are, however, a number of key differences between experiments investigating visual and rummage search, which make it difficult to develop an understanding of RS exclusively from visual search. Most importantly, visual search experiments are presented on a computer screen (see Chan & Hayward, 2013; Eckstein, 2011 for a recent review), and typically use simplified static stimuli such as colored shapes or lines (Treisman & Gelade, 1980), where targets and distractors do not overlap (though see Solman, Cheyne, & Smilek, 2012). In contrast, RS search is large-scale, requires both visual and haptic search, and targets can be both complex, and hidden or partially obscured.

The handful of studies that have explored aspects of RS have shown some striking results that stand in contrast to visual search behavior observed in the laboratory. First, while objects are often revisited in visual search tasks (Posner & Cohen, 1984; see also Klein, 2000), this is rarely the case in search where participants have to walk through the environment to uncover targets and distractors (Gilchrist et al., 2001; Smith et al., 2008). Second, while target salience is a cue known to be important for increasing the speed of visual search (Itti & Koch, 2000, 2001), this has been found to only be true in RS if participants are primed to highly salient cues (Foulsham et al., 2014). Third, when free to walk around a search space, searchers are able to learn regularities in the environment (i.e. where a target is likely to appear) even across changes in viewpoint or perspective (Jiang et al., 2014); a finding which differs from visual search (Jiang, Swallow, & Capistrano, 2013). These results suggest RS may rely on a structured path rather than simply visual guidance to aid search. If so, then a first attribute for effective RS is the ability to plan and follow a search path.

We have recently reported evidence consistent with this conclusion when showing that participants can have a shared understanding of what constitutes a systematic search path (Riggs et al., 2017). In the Riggs et al. (2017) task, participants searched an area of open grassland for an unknown number of hard-to-find coin targets. While searching, participants invariably followed an ‘S’ shaped search path. The ‘S’ shaped search path remained unchanged over variations in target number and performance accuracy.[[1]](#footnote-2) In this regard, we suggest that there is a common understanding of what constitutes a systematic search path when multiple targets are randomly distributed over the search space. Ruddle, Payne and Jones (1999) reported a similar finding in a search task in which participants searched for common objects in images representing a birds-eye view of a seascape. In their task, the objects were made hard-to-find by making them very small. Participants adopted a “lawn-mower” strategy, i.e. to search in parallel regular back-and-forth sweeps from one end of the search area to the other when landmarks were absent from the seascape. This strategy of back-and-forth sweeps was moderated when landmarks were present in the seascape.

Gilchrist and Harvey (2006) also found evidence of a systematic path in eye movements made when scanning a computer display for a target. When searching a regular grid layout, participants made more horizontal than vertical saccades. The systematic nature of eye movements made in search was lessened, but not removed by manipulating the regularity of the grid.

Searching in more complex spaces like virtual mazes (Buechner, Hölscher, & Wiener, 2009) and in rooms when blindfolded (Tellevik, 1992) can lead to a “perimeter” or “reference point” strategy. A perimeter strategy describes search along the outside of the search space and then into the center. A reference point strategy uses landmarks to order search. Buechner et al. (2009) suggested that search strategy will depend on both the environment itself, and the prior knowledge observers have about the environment.

In the task of RS in a house, options to consider in planning search, may be influenced by the presence of furniture and fixtures that constrain what path might be taken. In RS, the area surrounding the search path requires more than eye movements to find targets. Successful RS requires making head and body movements such that the affordance of all possible target areas can be identified. Using a term taken from studies of search and rescue, we refer to the width of the area around an individual that can be searched effectively given a set of eye, head and body movements as the Effective Search Width (ESW; Koopman, 1946, 1980). In the general case, the technical limits of sensors (human vision, radar etc.), determines the width of the ESW (Riggs et al., 2017). Possible target locations that sit outside of the limits of the ESW may not be identified as such. The second attribute we suggest is important for effective RS is to calibrate the path taken such that identification of possible target locations and their nature is possible. By nature of possible target locations, we mean understanding the actions required to overcome the affordance of the environment to contain or hide targets.

The need for RS to go beyond a purely visually guided target search is a consequence of the fact that at any location targets might not be in plain view (i.e. targets might be occluded or hidden). In these circumstances, rummage searchers may need to implement planned actions to counteract the affordances of the environment to hide objects. For example, targets might be hidden behind objects that need to be moved, or placed inside other objects that need to be opened or compressed (e.g., cupboards or cushions). As such, the third attribute of effective RS is to be able to implement the actions required to counteract the affordances of the environment to hide objects. In summary, we consider that there are three core attributes of RS. The ability to 1) define and follow a structured path, 2) fixate all possible target locations along that path and 3) search all possible target locations exhaustively, therefore encoding the affordances of environments to hide objects.

In the present study, we are interested in the type of RS that occurs in a security critical environment, specifically, when searching for evidence associated with criminal or terrorist activity. In such situations, RS must be exhaustive as the risks associated with failing to find *all* possible targets are high. When the task is to find clues to a murder, failing to find all targets can lead to failed convictions; when the task is to find IEDs, failure to find all targets can lead to injury and even death. We suggest that exhaustive RS requires faultlessly performing in accordance with each of the three attributes listed above.

Whether rummage searchers can ensure all targets and potential target locations are fixated and exhaustively searched is the question explored in the present study. There are no data currently available that speak to this issue. Returning to consideration of visual search, what we do know is that the capacity to conduct exhaustive visual search for targets is rather poor. In the case of visual search for rare or multiple targets, a number of studies have shown preventing an early termination of visual search to be a real challenge. For example, searching is known to be incomplete for infrequently occurring targets (Godwin et al., 2010; Wolfe et al., 2007), when searching for more than one instance of a target (Cain & Mitroff, 2013; Tuddenham, 1962), searching for two target types simultaneously (Menneer, Barrett, Phillips, Donnelly, & Cave, 2007), or searching for an unknown number of targets (Cain, Vul, Clark, & Mitroff, 2012; Wolfe, 2013). Recently we have shown that the effects of infrequently occurring targets on visual search result in both terminating search before all items have been explored and the rejection of targets even when fixated (Godwin, Menneer, Riggs, Cave, & Donnelly, 2015). Additionally, Solman, Hickey and Smilek (2014) found that targets could be missed even when engaged with. In their task participants were required to use their mouse to move stacked objects in what they termed a “manually-assisted search task”. Over 90% of target misses occurred despite participants having moved the target item. Solman et al. (2014) suggested that participants did not allow enough time to adequately inspect or process the item being moved. This “unpacking error” was more likely to occur in conditions of infrequently occurring targets. While these data from visual search studies might not be directly relevant to RS, they certainly raise the concern that participants conducting RS may not be comprehensive in identifying potential target locations, or exhaustive in searching those potential target locations effectively.

In the present study, participants engaged in RS of a residential house for incriminating evidence about a crime. Participants were given a briefing and asked to search for targets relevant to the brief. They were instructed to locate any firearms or money associated with a robbery at a bank, and any drugs that may be present at the property too. Participants did not know the number, location or distribution of potential targets. There were, in fact, six targets that varied in type and size (a small and large gun, a small and large roll of money and a small and large quantity of ‘drugs’). One target was plainly visible, some could be found after moving or opening objects and some required careful haptic examination in order to be found. Borrowing a term from eye movement research, areas that could hold targets were defined as regions of interest (ROIs).

The house was coded into separate ROIs which were operationalized in terms of three possible outcomes. Participants might engage in; first, a visual inspection of visible areas (e.g., a table top); second, visual inspection that would be improved by moving an object (e.g., an ornament) that might act as an occluder or opening (e.g., a cupboard door) objects; and third, haptic examination of spaces (e.g., the inside of a hidden cupboard) or objects (e.g., the compressing of a cushion) where visual inspection alone would have been incomplete. RS behaviour was examined by response accuracy, search time, measures of haptic action, indices of search strategy, and a series of eye movement measures. The use of mobile eye movement technology and the accompanying measures allowed us to determine which ROIs had been attended, and the actions made in respect of those ROIs.

The methodological approach, response taxonomy and performance measures taken in the present study emerged out of extensive pilot testing performed in conjunction with military trainers. We first tested pairs of expert rummage searchers (expert dyads). Expert rummage searchers typically work in pairs and we did not want to change their normal working practice, which requires them to double-check each other, for an exhaustive search of all possible target locations. This is because of the requirement to ensure all possible targets are found when the consequence of failing to find targets is severe. We would expect the expert searchers to engage in a complete and exhaustive search of ROIs. By complete we mean fixating all possible target locations AND by exhaustive we mean examining each of the attended locations to the extent required to determine the presence or absence of a target. These two indices (fixation of possible target locations and exhaustiveness of search) are independent but we expected experts to score highly on each index of performance.

To explore RS in an untrained population, we also tested a group of novice participants. These novice participants were either tested in pairs (novice dyads) like the experts, or as novice individuals searching alone. Although the experts were trained to work as a pair, we did not know whether this would help or hinder the novices. It seemed possible to us that novices may feel subject to less social pressure to terminate search if working alone than as part of a dyad. If so, novices may show their fundamental ability to search exhaustively better when searching alone than as part of a dyad. For a fair comparison with experts, we tested both novice dyads and novice individuals. It might be that both novice groups differ from the experts, but for our final conclusion in respect of the difference between expert and novice rummage searchers we will be based on whichever novice group is the least different from the experts. We expected to find evidence that experts would conduct a complete and exhaustive RS but novices would not. Whether misses in RS would result for novices from incomplete and inexhaustive search is an open question.

The simple hypothesis that we explored in this study was that novices would miss targets in RS through a failure to fixate all possible target locations and a failure to search all fixated potential target locations exhaustively. In other words, we predicted that, in contrast to experts, novices would fixate fewer ROIs and explore these ROIs less exhaustively. Furthermore, we predicted that participants would be less likely to be exhaustive as the motoric effort required to effectively search a ROI increased. For instance, participants would be more likely to carry out an exhaustive search on a ROI that required an object to be moved, than on a ROI that required full haptic examination. We will consider the results as evidence for validation of the RS framework if it helps to capture the differences between expert and novice searchers in a meaningful way. If the framework is validated then it will provide a taxonomy that may be useful to future researchers and an analysis potentially helpful in developing training.

## Method

### *Participants*

Seventy-four participants (39 males and 35 females, mean age = 24.97 years, SD = 4.85) with normal or corrected-to-normal color vision took part in the study. Sixteen participants formed eight expert dyads and were military volunteers from the Royal Logistic Corps who had completed search training. They took part for payment at the military volunteer standard rate (approximately £15 in total). Forty-eight participants recruited from the University of Southampton community formed twenty-four novice dyads and took part in the study for either course credit or payment (approximately £12). Ten more participants from the University of Southampton searched individually as novice individuals[[2]](#footnote-3). Participants were screened to ensure visual acuity and normal color vision using Snellen (1862) chart for visual acuity and the Ishihara (1917) color plates. The study was performed in accordance with the Declaration of Helsinki and was approved by the University of Southampton, School of Psychology ethics committee; informed consent was obtained from all participants.

### *Apparatus*

Eye movements were recorded using an Ergoneers Dikablis wireless head mounted eye tracking system consisting of two small cameras (one directed toward the scene, one toward the eye) mounted upon a lightweight pair of spectacles. Both cameras were accurate to 0.5 degrees of visual angle, operating at 25 Hertz (Hz), sampling the environment and eye every 40 milliseconds. The video footage was wirelessly transmitted to a pair of host laptops.

### *Stimuli*

The experiment was conducted within four rooms (Kitchen, Living Room, Large Bedroom and Small Bedroom) of a fully furnished residential house (see Figure 1). The rooms differed in their structure, function, form and size. The rooms were treated as a single trial. There was no particular interest in differences between rooms and so they are not considered further.

Insert Figure 1 about here

Figure 1*.* The four rooms of the fully furnished residential house. The Kitchen (a); Living Room (b); Large Bedroom (c) and Small Bedroom (d).

ROIs were defined as items of furniture (such as the bed, the desk, the wardrobe), other individual items (e.g. paintings), or sets of items (e.g. shelves of books and records) etc. Wall and floor surfaces were not coded as ROIs.

ROIs were coded in terms of the actions required to search them exhaustively (visual inspection, visual inspection involving the movement of objects, or haptic examination following visual inspection (and possibly object movement)). Although a participant could engage in visual inspection alone, no ROI could be searched exhaustively by just visual inspection alone (i.e. all ROIs required at least moving or opening an object). Although one of the targets was detectable by visual inspection alone, that target was positioned on a defined ROI that also required the moving of objects for search to be exhaustive; e.g. a windowsill which had multiple items along it. A ROI *could* have required visual inspection alone, but the coding of *our* ROIs as items of furniture or sets of items meant that all ROI required at least some action to be searched exhaustively. For a full list of ROIs and the set of actions required to conduct a full RS, see Appendix A. The order in which the rooms were searched was controlled using a Latin Square design.

The targets (see Figure 2) were representative of a crime scene evidence detection scenario. The number of targets was varied across rooms, with three located in the Small Bedroom, two in the Living Room one in the Large Bedroom and zero in the Kitchen (see Table 1). Targets were placed in the same locations for all participants.

Insert Figure 2 about here

Figure 2. The targets used in the RS.

### *Procedure*

Following successful screening for visual function, participants were required to read through a short PowerPoint presentation explaining the RS task and crime scenario briefing[[3]](#footnote-4). During this presentation, photographs of four guns, four rolls of cash, and four packets of drugs were shown. These photographs were not the actual targets, but provided generic exemplars of the types of targets hidden in the house. Once fitted with the eye tracker, participants completed a nine-point calibration procedure, which was repeated between rooms of the house. To validate this, participants were asked to view the nine-points a second time, which allowed judgment of the degree of overlap between the gaze position and the calibration dot. Prior to testing, the importance of being careful with the eye tracker was reinforced. Significant movement of the eye tracker on the participants’ heads could be detected on the video footage. If this was detected during the experiment, testing was paused temporarily to allow the eye tracker to be checked and recalibrated if required. This occurred very infrequently.

Participants were informed that an armed robbery had recently taken place, and that they were to search for incriminating evidence. They were instructed to search each room until they (or the dyad) were confident they had completed their search of that room. Once they had completed the search of a given room, they were shown to the next room to be searched. They were not allowed to return to rooms once they had determined that a room had been searched thoroughly.

Participants working as individual searchers completed the task alone, and novice dyads were told of the importance of working together to search as accurately and efficiently as possible. No instruction or guidance was given to assist with determining a strategy for pairs to work together. Experts searched as per their standard instructions.

## Results

The point of fixation was overlaid on the video of the room view from each participant and then the marked video was used for coding the data. The coding of each video was very time consuming and was carried out twice for each participant. The first pass through the video identified the ROIs fixated. The second pass through scored the action performed at each ROI fixated. It was not practicable or possible to carry out a double-blind coding procedure, as the identity of the participants (experts versus novices, dyads versus individuals) was clearly visible to the coder on the video stream. In order to validate the coding, two specially trained coders carried out all coding. The coding of dyads was split so that each coder coded an individual within each dyad. Please see the online supplementary material for a sample of the annotated video footage.

The coding of the action(s) performed at each ROI fixated was used to examine how exhaustively participants searched ROIs. Exhaustiveness might require (1) visual inspection, (2) visual inspection following moving or opening an object(s), or (3) haptic examination (following moving or opening an object(s)). In practice, and due to how the environment was constructed (ROIs were defined as items of furniture and sets of items), there were no ROIs that could be searched exhaustively by just initial visual inspection alone, that is to say, all ROIs required at least an object to be moved, or a container to be opened for exhaustive search. Failure to perform the full set of actions required for exhaustive search was coded as an incomplete search. See Table 1 for three examples of ROIs and the actions required to search them. See Appendix A for a full break down of all ROIs.

It is important to note, that as this is a naturalistic experiment it was difficult to control for the size of ROIs across type of actions required to search them. To partially overcome this difficulty we split the ROIs into categories of small (e.g., small individual objects, drawers etc.) and large (e.g. large objects, surfaces etc.). In fact, splitting ROIs into small and large categories showed that ROIs requiring haptic examination were more likely to be large than small (summed across rooms, 26 large ROIs versus 7 small ROIs), with the opposite being true for those requiring the moving or opening of objects (11 large ROIs versus 15 small ROIs). A Fisher exact test showed this contrast to be significant (*p* = .006). We return to consider the implications of this issue for the interpretation of our results in the Discussion.

Table 1.

*Example ROIs.*

Insert Table 1 about here

Three examples of ROIs and the actions required to search them.

#### Accuracy in Detecting Targets

Mean target detection rate was 92% (SD=18%) for the expert dyads, 59% (SD=19%) for the novice dyads and 68% (SD=34%) for the individual searchers (see Table 2 for the accuracy rate broken down by target type). One sample *t-*tests, comparing accuracy rates against ceiling (100%), showed both the individual and novice dyads performed significantly below ceiling (*t*(9) = 2.967, *p* = .016; *t*(23) = -10.552, *p* < .001), but the expert dyads were at ceiling (*t*(7) = -1.323, *p* = .228). A

one way ANOVA revealed a main effect of Group (*F*(2, 39) = 6.003, *p* = .005, ges = .235). Expert dyads were significantly more accurate than the novice dyads (*p* = .004). No other contrasts reached significance (*ps* > .119).

Table 2.

*Target Accuracy.*

Insert Table 2 about here

The proportion of each participant group to detect each of the targets.

#### Total Search Time

Search time was measured from the start of the first gaze on a ROI in a given room, to the end of the final gaze on a ROI in a given room. Participants indicated to the experimenters once they had completed their search of a room. With respect to dyads the end of search was measured when both searchers agreed that search was complete. Times for each room were summed to produce a total search time for RS of all rooms used in the house. The time for dyads is the search time for the pair (and not the time for each participant summed across both participants). Total search time was 01:03:28 (SD=00:20:33) hours, minutes and seconds for the expert dyads, 26:18 (SD=15:08) minutes and seconds for the novice dyads and 49:57 (SD=20:57) minutes and seconds for the individual searchers. A one way ANOVA revealed a main effect of Group (*F*(2, 39) = 13.455, *p* < .001, ges = .408). Novice dyads took significantly less time to search than the novice individuals (*p* = .007) and the expert dyads (*p* < .001). No other contrasts were significant (*ps* = .434).

#### Proportion of ROIs Fixated

Proportion of ROIs fixated revealed whether ROIs were fixated, and therefore, might have been identified as potential target locations. This was computed for dyads after summing across each member of the dyad. The expert dyads performed at ceiling with every pair fixating every ROI from each ROI type (those requiring opening and/or moving object(s) and those requiring haptic examination). For this reason they were not included in the analysis of Fixated ROIs. For both the novice dyads and the novice individuals, fixating either type of ROI, was significantly different from ceiling (*ps* < .001). A two (ROI type) by two (Group type) ANOVA revealed a main effect for ROI type (*F*(1, 32) = 18.048, *p* < .001, ges = .165 see Figure 3a) and Group (*F*(1, 32) = 37.344, *p* < .001, ges = .431). Participants were more likely to fixate ROIs where haptic examination was required than those requiring visual inspection after opening and/or moving objects and novice dyads fixated more ROIs than novice individuals.

The interaction between Group and ROI type was also significant (*F*(1, 32) = 11.385, *p* = .002, ges = .111). While both groups were more likely to fixate ROIs requiring haptic examination than opening and/or moving object(s) (*ps <* .014), the difference between ROI type was much larger for novice dyads (*p* = .003) than novice individuals (*p* = .014). Novice dyads were significantly more likely to fixate ROIs requiring opening and/or moving object(s) than the novice individuals (see Figure 3a).

***Search Exhaustiveness of Fixated ROIs***

For those ROIs that participants fixated, the likelihood that an exhaustive search followed can be calculated as the mean deviation from that required for an exhaustive search of ROIs of that type. A score was calculated for each participant/dyad by subtracting the score associated with the actual search action performed at each particular ROI from that required for an exhaustive search. For example, if a participant performed only a visual inspection of an ROI that required haptic search then that would give a deviation score of -2, as they had failed to move and/or open objects AND conduct a haptic examination. If they performed a visual inspection following movement on that ROI, then they would score -1. If the participant carried out the correct search action for that ROI (haptic search) then they would score 0 (i.e. no deviation from that required for an exhaustive search of that ROI).

A mean score was calculated across all ROIs of each type, with this score normalized by the maximum score possible (-1 for ROIs requiring opening and/or moving objects and -2 for ROIs requiring haptic search). A two (ROI type) by three (Group type) ANOVA revealed a main effect of Group (*F*(2, 39) = 7.034, *p* < .003, ges = .188) but the main effect of ROI type did not reach significance (*F*(1, 39) = 2.62, p=.114, ges=.024, see Figure 3b). The Expert dyads searched more exhaustively than the novice dyads (*p* < .001). The difference between novice dyads and novice individuals just missed significance (*p* = .0725). The difference between expert dyads and novice individuals was not significant (*p* = .281). The interaction between ROI type and Group did not reach significance (*F*(2, 39) = .172, *p* = .84, ges = .003).

### Insert Figure 3 about here

Figure 3. The proportion of ROIs fixated that should be searched by visual inspection following opening and/or moving objects (action) or haptic examination (with SEM) (a) and Mean deviation from the maximum possible search outcome for each ROI (with SEM) for novice individuals, novice dyads and expert dyads (b).

Overall we confirmed that the RS of expert dyads fixated all ROIs and searched them in a close to exhaustive manner. In contrast, both novice dyads and individual searchers were incomplete in their fixation of possible target locations though novice dyads fixated more ROIs than individuals. Novice dyads and individuals were also inexhaustive in their search of the possible target locations they fixated though there was a clear trend for novice dyads to search less exhaustively than individuals. The contrasting results across novice dyads and individuals suggest dyadic search in novices increases the number of possible target locations fixated but reduces the exhaustiveness of their search.

### *Additional Analyses*

To provide a more complete understanding of RS behavior, three further analyses were conducted. First, an analysis of the extent to which dyads overlapped in their patterns of inspection. Second, an analysis of the number of moves made per ROI searched. Third an analysis of basic eye movement measures. All analyses were computed irrespective of type of ROI, as determination of ROI requires at least some period of initial inspection in order for the determination to be made.

#### Overlap

An overlap of 0% would be consistent with pairs splitting the rummage task perfectly, whereas an overlap of 100% would indicate pairs searched the same ROIs. The novice and expert dyads differed in their amount of overlap (*t*(12.44) = -3.03, *p* = .01). Expert dyads overlapped in fixating 91% (SD=19%) of the same ROIs and the novice dyads overlapped in fixating 67% (SD=20%) of ROIs. Furthermore, by taking the probability of fixating ROI for the individual searchers (82% across both ROI types), the joint probability of two independent searchers both fixating 82% of ROI can be calculated. This gives us an estimate of 67% of overlap between two individuals conducting independent RS. Whereas expert dyads overlap a lot more in their RS as per their training, the performance of novice dyads is consistent with them performing two independent searches.

#### Number of Moves Made for Each ROI Searched

We focussed this analysis on the small bedroom as this had the lowest total number of ROIs and the least amount of tiering of ROIs (i.e. higher or lower altitude). ROIs were numbered sequentially based on their relative position. Moves between ROIs were scored as follows. If a participant moved without deviation between two neighbouring ROIs they were awarded a score 1, whereas if they missed out an intervening ROI between ROIs they were awarded a score 2, and so on. The smallest number of moves possible while visiting all of the 9 ROIs in the single bedroom would be 8 moves. The number of moves made while searching by participants was normalised by the number of ROIs visited (to calculate the fewest number of steps required to view all ROIs visited). Systematic search would tend to lower move counts relative to less systematic search. Scores would be raised by non-systematic search and by re-checking.

The data show that, on average, the expert dyads made 2.14 moves per ROI visited, while novice dyads made 3.67 and the individuals made 1.58 moves per ROI visited. Independent t-tests revealed the expert dyads made fewer moves per ROI than the novice dyads (t(61.68) = -4.72, p < .001), while the individuals made fewer moves per ROI than the expert dyads and the novice dyads (t(22.57) = -2.48, p = .021; t(53.25) = -6.69, p < .001 respectively).

#### Additional Eye Movement Measures

The eye movement data also allowed measurement of information processing during RS. Eye movements for dyads were from individuals within dyads. Eye movement analyses were conducted using a one-way ANOVA repeated over the Group factor (Group: novice individuals, novice dyads, expert dyads). Significant main effects were broken down using Bonferroni corrected t-tests. Three eye movement measures were examined based on gaze behavior, that is, the period of time spent fixating a ROI before moving the eyes away from that ROI; (1) Mean number of gazes, calculated as the average number of gazes made during the task (2) Mean gaze duration, calculated as the average length of time for a gaze and (3) Proportion of time spent fixating ROIs, calculated as the proportion of time spent fixating ROI relative to the total gaze time overall.

For mean number of gazes, the main effect of Group was not significant (*F*(2, 71) = 1.355, *p* = .264, ges = .037, see Figure 4a). For mean gaze duration, the main effect of Group was significant (*F*(2, 71) = 40.295, *p* < .001, ges = .531, see Figure 4b), with novice dyads making shorter gaze durations than both novice individuals (*p* < .001) and expert dyads (*p* < .001), however, there was no difference between the novice individuals and the expert dyads in relation to gaze (*p* = . 99). For the proportion of time spent fixating ROIs, the main effect of Group was significant (*F*(2, 71) = 3.171, *p* = .048, ges = .082 see Figure 4c), but no pairwise contrasts reached significance.

These additional analyses provide further evidence to suggest RS by novice dyads is problematic. The data are consistent with individuals within the novice dyads searching independently in an inefficient manner, and making relatively brief fixations to ROIs.

### Insert Figure 4 about here

Figure 4. Proportion of time spent fixating ROIs (with SEM) (a), Mean gaze duration (with SEM) (b), and Mean number of gazes (with SEM) (c), for novice individuals, novice dyads and expert dyads.

## Discussion

The goal of the present experiment was to explore RS in a security critical environment, specifically, when searching for evidence associated with a crime. In particular, we wished to explore two reasons for failing to find targets in a RS task: is it because ROIs holding targets are not fixated, or is it because the actions conducted are insufficient to thoroughly search the ROIs that are fixated. These questions were explored in relation to experts and novices working in dyads, justified on the grounds that expert rummage searchers typically work in pairs. They were also explored in relation to novice individuals searching alone.

We first developed a framework for classifying the fixations to ROIs and the motoric actions made to explore the ROIs fixated. The framework provided a conceptual distinction between three classes of action that, if poorly executed during RS, might lead to targets being missed. The data showed expert dyads were at ceiling for target detection and fixation of potential target locations, and to be very close to ensuring all ROIs fixated were searched exhaustively. In addition, and consistent with their training, expert dyads overlapped on almost all the ROIs they searched, searching reasonably systematically, consistent with use of a double-checking procedure. With respect to the three attributes required for excellent RS that informed the framework used for coding performance, these data are consistent with experts 1) following a structured path, 2) fixating all possible target locations along that path and 3) searching all possible target locations reasonably exhaustively, therefore encoding the affordances of environments to hide objects.

Evidence that expert dyads conducted a complete and exhaustive RS is reminiscent of that reported in other security related searches. Biggs, Cain, Clark, Darling, & Mitroff (2013) and Biggs & Mitroff (2013) tested airport security luggage screeners and found that in comparison to student searchers, airport security searchers were more accurate, took less time to locate a target, and critically, spent longer searching the display before terminating their search (Biggs et al., 2013). A part of the skill of being an expert is to calibrate how much time is required to search effectively and to not terminate search before that time occurs.

With respect to the novice rummage searchers (searching in dyads or as individuals), we sought to determine the best novice group to compare with the expert dyads. This turned out to be more complicated to determine than we originally envisaged it might be. The data suggest that working in dyads, relative to working alone, increased the number of potential target locations fixated but reduced the quality of search, reflected in the low mean gaze duration and exhaustiveness of search with ROIs. Although the novice dyads examined more ROIs than novice individuals, they become more superficial in their search. The impression of a superficial RS being conducted by novice dyads also emerges from the high number of moves made per ROI searched relative to both other groups. It is possible that when working together in a dyad, without the necessary training, novice participants are subject to social influence such as social loafing (Karau & Williams, 1993). They may think they appear to be searching efficiently by viewing more ROIs, but are actually searching them for less time less exhaustively and less systematic. Where novice dyads and individuals differ with experts, the most conservative comparison tends to be with novice individuals.

Relative to experts, novices missed targets through failing to fixate some ROIs, and failing to search exhaustively those ROIs that were fixated. These failures occurred despite evidence that the RS task was conducted diligently (the time difference in search between expert dyads and novice individuals was not significant) and systematically (the eye movement data showed no differences between expert dyads and novice individuals, and the number of moves per ROI was actually fewer for the individuals, but the individuals failed to fixate all ROIs present). It seems likely that the experts just ‘see’ the search environment differently to novices.

As such, knowing what to search and appreciating the affordances of how environments can hide targets are skills improved by training. Visual expertise is often considered as being reflected in the familiarity and exposure to classes of stimuli [expertise effects have previously been shown to exist in a range of domains such as medicine (Krupinski et al., 1996, 2006; Kundel & Nodine, 1983; Kundel, Nodine, Conant, & Weinstein, 2007; Kundel & La Follette, 1972; Nodine, Mello-Thoms, Kundel, & Weinstein, 2002), sport (Howard, Troscianko, & Gilchrist, 2010; Land & McLeod, 2000) and reading music (Rayner & Pollatsek, 1997)]. Furthermore, we have also shown effects of experience on decision-making with respect to the presence of IEDs, consistent with learning the affordances of environments to hide targets (Godwin et al., 2015). With respect to the current study, expertise is manifested in understanding of the affordance of a residential house to hide targets. To some extent, this is a surprising outcome given that a residential house was a familiar environment to all our participants. It cannot, therefore, be the visual context itself with which we need to become more familiar but its potential to afford hiding. Evidently, it is the act of exhaustive searching within this context that requires training.

One final point to note with respect to the results is that we found no evidence to support the hypothesis that participants would be less exhaustive as the motoric effort to effectively search a ROI increased.

The present experiment was novel. The reality of RS was maintained in the real world, at the expense of close control over that environment, to explore a framework for understanding rummage searching. The lack of close control of the environment is problematic for the present study in at least one way. It is the case that the ROIs described in terms of the actions required to search them (opening and/or movement versus haptic examination) also varied in size. ROIs requiring haptic search tended to be bigger than those requiring moving or opening of objects. These co-varying attributes make it difficult to determine the property(ies) responsible for behavioural differences. It may well be that the haptic ROIs were fixated more because they tended to be bigger. We acknowledge, however, that the issue of how best to consider ROI in terms of type and size is one that might be clarified with future work.

Testing search performance using an analytic framework for RS revealed data capturing expertise in RS. Experts ensure that they search all locations, and that they search those locations using all necessary actions. Furthermore, when searching as a dyad, pairs of experts engage in overlapping, systematic search consistent with a re-checking strategy. These search skills and strategy raise the target detection rate beyond that achieved by novices, either searching alone or in dyads, when searching for targets in a residential house. Raising the performance level of RS by novices to that of experts will require training in ensuring all possible target locations are fixated, the actions required to search those locations are understood, and that the actions are conducted effectively. In addition, if searching as part of a dyad, novices must be trained not just in RS skills but also in how to maintain search quality and coordinate search across individuals.

Finally, in outlining our framework for understanding RS and showing how it is helpful in discriminating expert from novice searchers, we are aware of important challenges for future work. For example, we did not gather data about ROIs that contained targets, but were explored and rejected as holding targets. To do so would require some other evidence of decision making while performing the search task to understand recognition, interpretation and decision errors (Kundel, Nodine, & Carmody, 1978). Furthermore, we consider it critical to test whether the framework generalises such that it is similarly helpful in explaining data from other RS scenarios.

**References**

Biggs, A. T., Cain, M. S., Clark, K., Darling, E. F., & Mitroff, S. R. (2013). Assessing visual search performance differences between Transportation Security Administration Officers and nonprofessional visual searchers. *Visual Cognition*, *21*(3), 330–352. http://doi.org/10.1080/13506285.2013.790329

Biggs, A. T., & Mitroff, S. R. (2013). Different predictors of multiple-target search accuracy between nonprofessional and professional visual searchers. *Quarterly Journal of Experimental Psychology*, *67*(7), 1335–1348. http://doi.org/10.1080/17470218.2013.859715

Buechner, S. J., Hölscher, C., & Wiener, J. M. (2009). Search Strategies and their Success in a Virtual Maze. In *Proceedings of the Cognitive Science Society*, (Vol. 31, No. 31).

Cain, M. S., & Mitroff, S. R. (2013). Memory for found targets interferes with subsequent performance in multiple-target visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1398–1408. http://doi.org/10.1037/a0030726

Cain, M. S., Vul, E., Clark, K., & Mitroff, S. R. (2012). A bayesian optimal foraging model of human visual search. *Psychological Science*, *23*(9), 1047–54. http://doi.org/10.1177/0956797612440460

Chan, L. K. H., & Hayward, W. G. (2013). Visual search. *Wiley Interdisciplinary Reviews: Cognitive Science*, *4*(4), 415–429. http://doi.org/10.1002/wcs.1235

Donnelly, N., Guest, R., Fairhurst, M., Potter, J., Deighton, A., & Patel, M. (1999). Developing algorithms to enhance the sensitivity of cancellation tests of visuospatial neglect. *Behavior Research Methods, Instruments, & Computers*, *31*(4), 668–673. http://doi.org/10.3758/BF03200743

Eckstein, M. P. (2011). Visual search: a retrospective. *Journal of Vision*, *11*(5:14), 1–36. http://doi.org/10.1167/11.5.14

Foulsham, T., Chapman, C., Nasiopoulos, E., & Kingstone, A. (2014). Top-Down and Bottom-Up Aspects of Active Search in a Real-World Environment. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, *68*(1), 8–19. http://doi.org/10.1037/cep0000004

Gilchrist, I., & Harvey, M. (2006). Evidence for a systematic component within scan paths in visual search. *Visual Cognition*, *14*(4–8), 704–715. http://doi.org/10.1080/13506280500193719

Gilchrist, I., North, A., & Hood, B. (2001). Is Visual Search Really Like Foraging? *Perception*, *30*(12), 1459–1464. Retrieved from http://pec.sagepub.com/content/30/12/1459.short

Godwin, H. J., Liversedge, S. P., Kirkby, J. A., Boardman, M., Cornes, K., & Donnelly, N. (2015). The influence of experience upon information-sampling and decision-making behaviour during risk assessment in military personnel. *Visual Cognition*, *23*(4), 415–431. http://doi.org/10.1080/13506285.2015.1030488

Godwin, H. J., Menneer, T., Cave, K. R., Helman, S., Way, R. L., & Donnelly, N. (2010). The impact of Relative Prevalence on dual-target search for threat items from airport X-ray screening. *Acta Psychologica*, *134*(1), 79–84. http://doi.org/10.1016/j.actpsy.2009.12.009

Godwin, H. J., Menneer, T., Riggs, C. A., Cave, K. R., & Donnelly, N. (2015). Perceptual failures in the selection and identification of low-prevalence targets in relative prevalence visual search. *Attention, Perception, & Psychophysics*, *77*(1), 150–159. http://doi.org/10.3758/s13414-014-0762-8

Howard, C. J., Troscianko, T., & Gilchrist, I. D. (2010). Eye-response lags during a continuous monitoring task. *Psychonomic Bulletin & Review*, *17*(5), 710–717. http://doi.org/10.3758/PBR.17.5.710

Ishihara, S. (1917). *Test for Colorblindness*. Tokyo: Hongo Harukichi.

Itti, L., & Koch, C. (2000). A Saliency-Based Search Mechanism for Overt and Covert Shifts of Visual Attention. *Vision Research*, *40*(10), 1489–1506. Retrieved from http://www.sciencedirect.com/science/article/pii/S0042698999001637

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, *2*(3), 194–203. Retrieved from http://www.nature.com/nrn/journal/v2/n3/abs/nrn0301\_194a.html

Jiang, Y. V, Swallow, K. M., & Capistrano, C. G. (2013). Visual search and location probability learning from variable perspectives. *Journal of Vision*, *13*(6), 13–13. http://doi.org/10.1167/13.6.13

Jiang, Y. V, Won, B.-Y., Swallow, K. M., & Mussack, D. M. (2014). Spatial reference frame of attention in a large outdoor environment. *Journal of Experimental Psychology. Human Perception and Performance*, *40*(4), 1346–57. http://doi.org/10.1037/a0036779

Karau, S., & Williams, K. (1993). Social Loafing: A Meta-Analytic Review nd Theoretical Integration. *Journal of Personality and Social Psychological*, *65*(4), 681–706. Retrieved from http://psycnet.apa.org/journals/psp/65/4/681/

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, *4*(4), 138–147. http://doi.org/10.1016/S1364-6613(00)01452-2

Koopman, B. O. (1946). *Search and Screening, Operations Evaluation Group Report 56*. Center for Naval Analysis, Alexandria, Virginia.

Koopman, B. O. (1980). *Search and screening: general principles with historical applications.* New York: Pergamon Press.

Krupinski, E. a. (1996). Visual scanning patterns of radiologists searching mammograms. *Academic Radiology*, *3*(2), 137–144. http://doi.org/10.1016/S1076-6332(05)80381-2

Krupinski, E. A., Tillack, A. A., Richter, L., Henderson, J. T., Bhattacharyya, A. K., Scott, K. M., … Weinstein, R. S. (2006). Eye-movement study and human performance using telepathology virtual slides. Implications for medical education and differences with experience. *Human Pathology*, *37*(12), 1543–1556. http://doi.org/10.1016/j.humpath.2006.08.024

Kundel, H. L., & La Follette, P. S. (1972). Visual search patterns and experience with radiological images. *Radiology*, *103*(3), 523–528. http://doi.org/10.1148/103.3.523

Kundel, H. L., & Nodine, C. F. (1983). A visual concept shapes image perception. *Radiology*, *146*(2), 363–368. http://doi.org/10.1148/radiology.146.2.6849084

Kundel, H. L., Nodine, C. F., Conant, E. F., & Weinstein, S. P. (2007). Holistic component of image perception in mammogram interpretation: gaze-tracking study. *Radiology*, *242*(2), 396–402. http://doi.org/10.1148/radiol.2422051997

Kundel, H., Nodine, C., & Carmody, D. (1978). Visual scanning, pattern recognition and decision-making in pulmonary nodule detection. *Investigative Radiology*, *13*(3), 175–181. Retrieved from http://journals.lww.com/investigativeradiology/Abstract/1978/05000/Visual\_Scanning,\_Pattern\_Recognition\_and.1.aspx

Land, M. F., & McLeod, P. (2000). From eye movements to actions: how batsmen hit the ball. *Nature Neuroscience*, *3*(12), 1340–5. http://doi.org/10.1038/81887

Menneer, T., Barrett, D. J. K., Phillips, L., Donnelly, N., & Cave, K. R. (2007). Costs in Searching for Two Targets: Dividing SearchAcross Target Types Could Improve Airport Security Screening. *Applied Cognitive Psychology*, *21*(7), 915–932. http://doi.org/10.1002/acp.1305

Nodine, C., Mello-Thoms, C., Kundel, H. L., & Weinstein, S. P. (2002). Time Course of Perception and Decision Making During Mammographic Interpretation. *American Journal of Roentgenology*, *179*(4), 917–923. http://doi.org/10.2214/ajr.179.4.1790917

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. *Attention and Performance: Control of Language Processes*, *32*, 531–556. http://doi.org/10.1162/jocn.1991.3.4.335

Rayner, K., & Pollatsek, A. (1997). the Eye-Hand Span , Eye Movements , and the Perceptual Span During of Music. *Current Directions in Psychological Science*, *6*(2), 49–53. Retrieved from http://www.jstor.org/stable/20182443

Riggs, C. A., Cornes, K., Godwin, H. J., Liversedge, S. P., Guest, R., & Donnelly, N. (2017). The importance of search strategy for finding targets in open terrain. *Cognitive Research: Principles and Implications*, *2*(1), 14. http://doi.org/10.1186/s41235-017-0049-4

Ruddle, R. A., Payne, S. J., & Jones, D. M. (1999). The effects of maps on navigation and search strategies in very-large-scale virtual environments. *Journal of Experimental Psychology: Applied*, *5*(1), 54. Retrieved from https://scholar.google.co.uk/scholar?hl=en&as\_sdt=0%2C5&q=Ruddle%2C+R.+A.%2C+Payne%2C+S.+J.%2C+%26+Jones%2C+D.+M.+%281999%29.+The+effects+of+maps+on+navigation+and+search+strategies+in+very-large-scale+virtual+environments.+Journal+of+Experimental+Psychol

Smith, A. D., Hood, B. M., & Gilchrist, I. D. (2008). Visual search and foraging compared in a large-scale search task. *Cognitive Processing*, *9*(2), 121–126. http://doi.org/10.1007/s10339-007-0200-0

Snellen, H. (1862). *Test-types for the determination of the acuteness of vision*. PW van de Weijer. Retrieved from http://dspace.library.uu.nl/handle/1874/328592

Solman, G. J. F., Cheyne, J. A., & Smilek, D. (2012). Found and missed: Failing to recognize a search target despite moving it. *Cognition*, *123*(1), 100–118. http://doi.org/10.1016/j.cognition.2011.12.006

Solman, G. J., Hickey, K., & Smilek, D. (2014). Comparing target detection errors in visual search and manually-assisted search. *Attention, Perception, & Psychophysics*, *76*(4), 945–958. http://doi.org/10.3758/s13414-014-0641-3

Tellevik, J. M. (1992). Influence of spatial exploration patterns on cognitive mapping by blindfolded sighted persons. *Journal of Visual Impairment & Blindness*, *86*(5), 221–224.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*(1), 97–136. http://doi.org/10.1016/0010-0285(80)90005-5

Tuddenham, W. J. (1962). Visual Search, Image Organization, and Reader Error in Roentgen Diagnosis: Studies of the Psychophysiology of Roentgen Image Perception Memorial Fund Lecture 1. *Radiology*, *78*(5), 694–704. http://doi.org/10.1148/78.5.694

Wolfe, J. M. (2013). When is it time to move to the next raspberry bush? Foraging rules in human visual search. *Journal of Vision*, *13*(3), 10. http://doi.org/10.1167/13.3.10

Wolfe, J. M., Horowitz, T. S., Van Wert, M. J., Kenner, N. M., Place, S. S., & Kibbi, N. (2007). Low target prevalence is a stubborn source of errors in visual search tasks. *Journal of Experimental Psychology: General*, *136*(4), 623–638. http://doi.org/10.1037/0096-3445.136.4.623

**Appendix A**

Table A1.

*Regions of Interest.*

Insert Table A1 about here

ROIs listed in clockwise direction starting from the door of each room. Target locations also indicated. Note, in the Kitchen the ROIs cabinet, drawer 1, drawer 2 and cupboard are part of a larger item of furniture and the work surfaces have been split into three. All other ROI are separate items.

**Tables and Figures**

**

Figure 1. The four rooms of the fully furnished residential house. The Kitchen (a); Living Room (b); Large Bedroom (c) and Small Bedroom (d).

**

Figure 2. The targets used in the RS.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Room | ROI | Search output required | Maximum search output | Target |
| Living Room | Cupboard | Visual inspection, including following opening of door and moving of vinyl records AND haptic examination of hard to see space. | Haptic examination | Large pack of drugs inside a box of vinyl records inside cupboard |
| Living Room | Picture | Visual inspection, including following moving of whole picture. | Visual inspection following movement |  |
| Living Room | Bookcase | Visual inspection, including following moving of books AND haptic examination of hard to see spaces. | Haptic examination | Small roll of money inside one of the game boxes on the bookshelf |

Table 1.

*Example ROIs.*

Three examples of ROIs and the actions required to search them.

Table 2.

*Target Accuracy.*

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | | |
|  | Target Accuracy | | |
|  | Novice Individuals | Novice Dyads | Expert Dyads |
| Large Drugs | 0.50 | 0.38 | 0.88 |
| Small Drugs | 0.50 | 0.17 | 0.75 |
| Large Gun | 0.80 | 0.88 | 1.00 |
| Small Gun | 0.80 | 0.92 | 1.00 |
| Large Money | 0.70 | 0.50 | 0.88 |
| Small Money | 0.90 | 0.71 | 1.00 |

The proportion of each participant group to detect each of the targets.

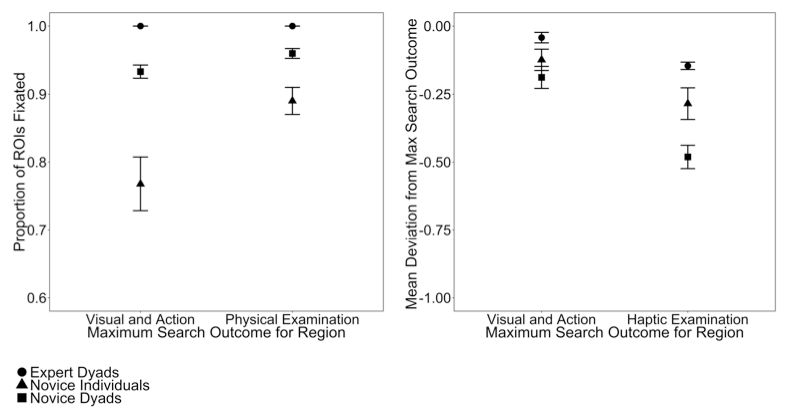


Figure 3. The proportion of ROIs fixated that should be searched by visual inspection following opening and/or moving objects (action) or haptic examination (with SEM) (a) and Mean deviation from the maximum possible search outcome for each ROI (with SEM) for novice individuals, novice dyads and expert dyads (b).

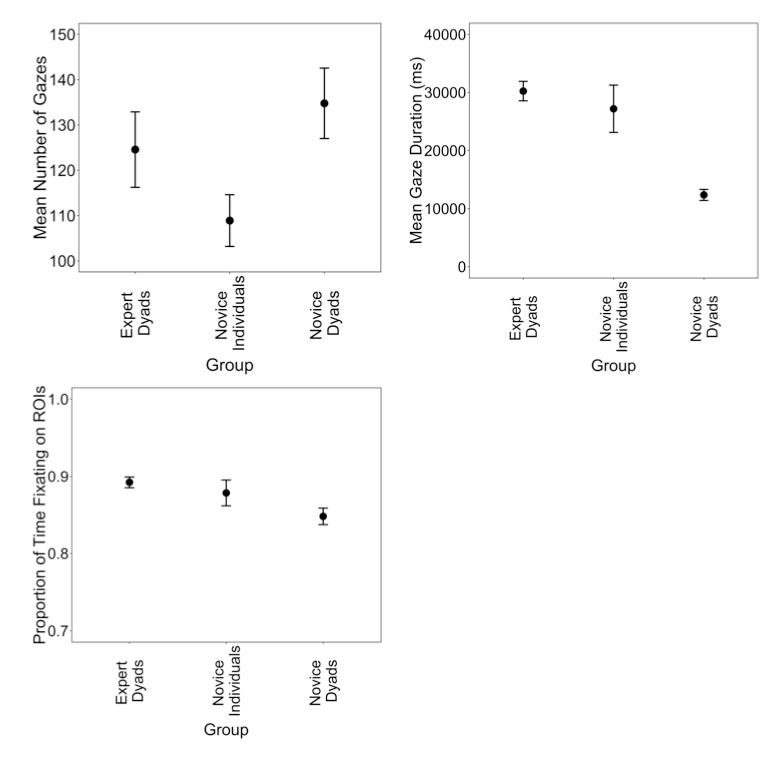
**

Figure 4. Proportion of time spent fixating ROIs (with SEM) (a), Mean gaze duration (with SEM) (b), and Mean number of gazes (with SEM) (c), for novice individuals, novice dyads and expert dyads.

**Appendix A**

Table A1.

*Regions of Interest.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Room | ROI | Search output required | Maximum search output | Target |
|  |  |  |  |  |
| Kitchen | Vacuum Cleaner | Visual inspection, including following opening of parts and moving whole vacuum cleaner. | Visual inspection following movement |  |
|  | Fridge Freezer | Visual inspection, including following opening of door and moving of water bottles. | Visual inspection following movement |  |
|  | Work surface 1 | Visual inspection, including following moving of items on the work surface. | Visual inspection following movement |  |
|  | Cupboard 1 | Visual inspection, including following opening of door and moving of crockery AND haptic examination of hard to see space. | Haptic examination |  |
|  | Cupboard 2 | Visual inspection, including following opening of door and moving of crockery AND haptic examination of hard to see space. | Haptic examination |  |
|  | Cupboard 3 | Visual inspection, including following opening of door and moving of crockery AND haptic examination of hard to see space. | Haptic examination |  |
|  | Bag | Visual inspection, including following opening of bag and moving contents (e.g. paper towels) and whole bag AND haptic examination (e.g. sides of bag and material inside). | Haptic examination |  |
|  | Window Sill | Visual inspection, including following moving of objects on the windowsill. | Visual inspection following movement |  |
|  | Work surface 2 | Visual inspection, including following moving of items on the work surface. | Visual inspection following movement |  |
|  | Mini Fridge | Visual inspection, including following opening of door. | Visual inspection following movement |  |
|  | Drawer 1 | Visual inspection, including following opening of door and moving of objects (e.g. cutlery) AND haptic examination of objects (e.g. packet of antibacterial wipes). | Haptic examination |  |
|  | Drawer 2 | Visual inspection, including following opening of door. | Visual inspection following movement |  |
|  | Cupboard 4 | Visual inspection, including following opening of door and moving of objects (e.g. crockery) AND haptic examination of hard to see space. | Haptic examination |  |
|  | Cupboard 5 | Visual inspection, including following opening of door and moving of objects (e.g. crockery) AND haptic examination of hard to see space. | Haptic examination |  |
|  | Work surface 3 | Visual inspection, including following moving of items on the work surface. | Visual inspection following movement |  |
|  | Drawer 3 | Visual inspection, including following opening of door and moving of objects (e.g. cutlery) AND haptic examination (e.g. packet of antibacterial wipes). | Haptic examination |  |
|  | Cupboard 6 | Visual inspection, including following opening of door and moving of objects (e.g. crockery) AND haptic examination of hard to see space. | Haptic examination |  |
|  | Bin | Visual inspection, including following moving of rubbish and whole bin. | Visual inspection following movement |  |
|  | Drawer 4 | Visual inspection, including following opening of door and moving of objects (e.g. cutlery) AND haptic examination of objects (e.g. packet of antibacterial wipes). | Haptic examination |  |
|  | Boiler | Visual inspection following opening of door. | Visual inspection following movement |  |
|  | Cupboard 7 | Visual inspection, including following opening of door and moving of objects (e.g. crockery) AND haptic examination of hard to see space. | Haptic examination |  |
|  | Clock | Visual inspection following moving of whole clock. |  |  |
|  | Radiator | Visual inspection AND haptic examination of space behind radiator. | Haptic examination |  |
|  |  |  |  |  |
| Living Room | Magazine Rack | Visual inspection, including following moving of individual magazines and whole magazine rack. | Visual inspection following movement |  |
|  | Cabinet | Visual inspection following opening of door and moving ornaments. | Visual inspection following movement |  |
|  | Drawer 1 | Visual inspection, including following opening of drawer. | Visual inspection following movement |  |
|  | Drawer 2 | Visual inspection, including following opening of drawer. | Visual inspection following movement |  |
|  | Cupboard | Visual inspection, including following opening of door and moving of vinyl records AND haptic examination of hard to see space. | Haptic examination | Large pack of drugs inside a box of vinyl records inside cupboard |
|  | Flower Pot | Visual inspection, including following moving of flowers and whole flowerpot. | Visual inspection following movement |  |
|  | Picture | Visual inspection, including following moving of whole picture. | Visual inspection following movement |  |
|  | Fireplace | Visual inspection, including following moving of items on the fireplace. |  |  |
|  | TV Unit | Visual inspection, including following moving of items on the unit. | Visual inspection following movement |  |
|  | Rug | Visual inspection, including following moving of whole rug. | Visual inspection following movement |  |
|  | Lamp | Visual inspection, including following moving of whole lamp AND haptic examination of inside of lampshade. | Haptic examination |  |
|  | Bin | Visual inspection, including following moving of items inside bin or whole bin. | Visual inspection following movement |  |
|  | Window sill | Visual inspection, including following moving of objects on the windowsill. | Visual inspection following movement |  |
|  | Radiator | Visual inspection AND haptic examination of space behind radiator. | Haptic examination |  |
|  | Bookcase | Visual inspection, including following moving of books AND haptic examination of hard to see spaces. | Haptic examination | Small roll of money inside one of the game boxes on the bookshelf |
|  | Glass Table | Visual inspection, including following moving of items on the table. | Visual inspection following movement |  |
|  | Sofa | Visual inspection, including following moving of cushions AND haptic examination of cushions. | Haptic examination |  |
|  |  |  |  |  |
| Large Bedroom | Chair | Visual inspection, including following moving of cushions AND haptic examination of cushions. | Haptic examination |  |
|  | Wardrobe | Visual inspection, including following opening of door and moving of objects (e.g. clothes and bedding) AND haptic examination of objects (e.g. clothes and bedding). | Haptic examination |  |
|  | Chest of Drawers | Visual inspection, including following opening of drawers and moving of clothes AND haptic examination of clothes. | Haptic examination |  |
|  | TV | Visual inspection following moving of whole TV. | Visual inspection following movement |  |
|  | Bedside Table | Visual inspection, including following opening of door and moving of boxes AND haptic examination of the underside of table. | Haptic examination |  |
|  | Window sill | Visual inspection following moving of items on windowsill. | Visual inspection following movement |  |
|  | Radiator | Visual inspection AND haptic examination of space behind radiator. | Haptic examination |  |
|  | Bed | Visual inspection, including following moving of objects (e.g. pillows) AND haptic examination of bedding and underside of bed. | Haptic examination |  |
|  | Bag | Visual inspection, including following opening of bag and moving (e.g. of sheets) AND haptic examination (e.g. sides of bag and sheets inside). | Haptic examination | A long barreled weapon (rifle) inside a bag under the bed |
|  |  |  |  |  |
| Small Bedroom | Desk | Visual inspection, including following opening of drawers and moving objects (e.g. stationary) AND haptic examination of hard to see spaces. | Haptic examination |  |
|  | Bean Bag | Visual inspection, including following opening of outer cover and moving whole beanbag AND haptic examination the beanbag. | Haptic examination | A large bundle of money inside the beanbag |
|  | Window sill | Visual inspection, including following moving of items on windowsill. | Visual inspection following movement | A small package of drugs placed on the windowsill |
|  | Radiator | Visual inspection AND haptic examination of space behind radiator. | Haptic examination |  |
|  | Chair | Visual inspection, including following moving of cushions AND haptic examination of cushions. | Haptic examination |  |
|  | Guitar | Visual inspection, including following moving of whole guitar. | Visual inspection following movement |  |
|  | Cupboard | Visual inspection, including following opening of door or moving of toys AND haptic examination of hard to see spaces. | Haptic examination | A short barreled weapon (pistol) inside the cupboard |
|  | Wardrobe | Visual inspection, including following opening of door or moving of clothes and bedding AND haptic examination of clothes and bedding. | Haptic examination |  |
|  | Bed | Visual inspection, including following moving of objects (e.g. of pillows) AND haptic examination of bedding and underside of bed. | Haptic examination |  |

ROIs listed in clockwise direction starting from the door of each room. Target locations also indicated. Note, in the Kitchen the ROIs cabinet, drawer 1, drawer 2 and cupboard are part of a larger item of furniture and the work surfaces have been split into three. All other ROI are separate items.

1. Interestingly, an ‘S’ shaped strategy is also commonly used in visuo-spatial cancellation tasks (Donnelly et al., 1999) where the path is determined by the order of cancellations. [↑](#footnote-ref-2)
2. A number of pragmatic concerns impacted the size of the participant groups. These concerns included limited access to the expert population and a fixed time limit restricting access to the experimental set-up. [↑](#footnote-ref-3)
3. While the basic presentation on RS was common across all participants, the naïve dyad participants were given different threat briefs (that the target spotted by an eye witness was congruent in size with the threat brief (n = 8), incongruent in size with the threat brief, i.e. the threat brief was inaccurate (n = 8) or a more general threat brief not specifying a specific target at all (n = 8)) or some additional details about rummage searching regarding possible sources of error (a form of error management training) (n=12) or no additional details (n = 12). Statistical comparisons of performance speed, accuracy and exhaustive search, as well as underlying eye movement measures showed that those receiving the basic information and those with minor variants differed on only 1 out of 16 tests. For this reason, we have collapsed participants across these minor variations to increase the statistical power of the study. Note, collapsing participant groups meant that the number of participants in the novice dyad condition was substantially larger than the other participant groups. [↑](#footnote-ref-4)