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Rare, but obviously there: Effects of target frequency and salience on visual search accuracy☆

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ABSTRACT

Accuracy can be extremely important for many visual search tasks. However, numerous factors work to undermine successful search. Several negative influences on search have been well studied, yet one potentially influential factor has gone almost entirely unexplored—namely, how is search performance affected by the likelihood that a specific target might appear? A recent study demonstrated that when specific targets appear infrequently (*i.e.*, once in every thousand trials) they were, on average, not often found. Even so, some infrequently appearing targets were actually found quite often, suggesting that the targets' frequency is not the only factor at play. Here, we investigated whether salience (*i.e.*, the extent to which an item stands out during search) could explain why some infrequent targets are easily found whereas others are almost never found. Using the mobile application *Airport Scanner*, we assessed how individual target frequency and salience interacted in a visual search task that included a wide array of targets and millions of trials. Target frequency and salience were both significant predictors of search accuracy, although target frequency explained more of the accuracy variance. Further, when examining only the rarest target items (those that appeared on less than 0.15% of all trials), there was a significant relationship between salience and accuracy such that less salient items were less likely to be found. Beyond implications for search theory, these data suggest significant vulnerability for real-world searches that involve targets that are both infrequent and hard-to-spot.

1. Introduction

Visual search—the act of finding targets among distractors—is a common activity conducted countless times every day; people regularly look for specific messages in their E-mail inbox, scan restaurant menus for their favorite meals, and look for their cars in a crowded parking lot. While accurately and efficiently completing such common visual searches is desirable, other search scenarios place a much higher priority on accuracy. For example, airport security screening and radiology demand high search accuracy as their outcomes can have life-or-death consequences. Unfortunately, a variety of factors can negatively influence search accuracy, and thus it is important to understand, and overcome, these influences.

Recent evidence has examined the influence of target prevalence—the likelihood of any target appearing during search—on visual search accuracy. While many laboratory-based search tasks employ a relatively high frequency rate (*e.g.*, most have a target present on 50% of the trials), many real-world searches—such as airport security screening and radiological cancer screening—are *rare-target searches* in which targets are only present on a very small percentage of trials. For example, the cancer rate in mammography is estimated at less than 5 cancers per 1000 examinations, or approximately 0.5% of cases examined (NCI, 2009). Searchers rarely encounter what they are trying to find when target prevalence is so low, and previous research has suggested that search accuracy is much lower for rarely appearing targets *versus* frequently appearing targets (*e.g.*, Godwin et al., 2010; Hon, Yap, & Jabar, 2013; Menneer, Donnelly, Godwin, & Cave, 2010; Rich et al., 2008; Wolfe & Van Wert, 2010; Wolfe, Horowitz, & Kenner, 2005; Wolfe et al., 2007; but see also Fleck & Mitroff, 2007). This effect has been demonstrated in cancer screening (Evans, Birdwell, & Wolfe, 2013; Evans, Tambouret, Wilbur, Evered, & Wolfe, 2011) and for newly trained airport baggage screeners (Wolfe, Brunelli, Rubinstein, & Horowitz, 2013).

While target prevalence has been the focus of recent investigations, a related influence has gone largely unstudied. Namely, distinct from how often *any* target might appear (*i.e.*, target prevalence), there is also variability across visual search tasks in how often a *specific* target might appear. That is, when there are multiple possible targets that can appear in a search environment, some of those targets may be present relatively more often than others regardless of overall target prevalence. For example, it is rare for any contraband item to appear

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in an airport X-ray image (*i.e.*, there is a low target prevalence rate), but among these targets, some items (*e.g.*, water bottles), are more likely to appear than others (*e.g.*, hand grenades). In this scenario, a water bottle would have a higher frequency rate than a hand grenade. We refer to this particular issue, the likelihood of a specific target appearing during a search as *individual target frequency* (ITF), and note that it is distinct from target prevalence—the likelihood of any target appearing during a given search.

We recently demonstrated that visual search accuracy can be dramatically impacted by ITF rates (Mitroff & Biggs, 2014). In our previous study, we assessed data from the mobile application *Airport Scanner* (Kedlin Co.; https://www.airportscannergame.com) to examine search accuracy for 78 unique targets that appeared throughout millions of trials. This immense dataset provided a means to examine the influences of ITF on accuracy across a range of frequency rates (from 0.08% to 3.70%), and for extraordinarily low frequency rates (thirty items had an ITF rate below 0.15%). The evidence showed a strong logarithmic relationship between ITF and search accuracy, with relatively accurate search performance above 1% ITF and a substantial decline in accuracy below 1% ITF. The thirty targets with an ITF rate below 0.15% (*i.e.*, each of the items appeared less than 15 times out of every 10,000 trials), which were referred to as "ultra-rare" items, had an average detection rate of 27%. This was relatively low compared to an average detection rate of 92% for the targets with an ITF rate above 1%. However, some of the ultra-rare items were often found (accuracy rates of approximately 75%) while others were almost never found (accuracy rates below 10%). This variability is intriguing, and it is important to understand why there would be such substantial differences in accuracy for ultra-rare targets. If ultra-rare items are generally harder to find, but some are actually quite easy to find, then determining what drives this variability can inform both search theory and practical implementations for real-world searches that include ultra-rare targets.

The most straightforward possible explanation for why some ultra-rare items may be found more often than others is that they "stand out more." Salience—how much an item stands out in a display—is a common concept in attention studies: "high-salience" is used to describe items that readily stand out, whereas "low-salience" is used to describe items that do not stand out (*e.g.*, Parkhurst, Law, & Niebur, 2002; Treue, 2003). Notably, differences in target salience are known to have robust influences on both search speed and search accuracy. For example, a singleton—an item that differs from the rest of the display on a single, basic feature dimension—often can be found very quickly despite many homogenous distractors in the display (Treisman & Gelade, 1980). The important point is that even very similar items could vary in how well they stand out.

Here we asked a simple question: Could salience explain why some ultra-rare targets are found more often than others? Although ITF and salience are both potent contributors to visual search accuracy, they have yet to be directly compared. Highly salient targets might be found very quickly and with high accuracy, but does that also mean a searcher would miss an infrequently appearing target no matter how prominent it was in the display? While this is a relatively straightforward question, it is not easily answered in a typical laboratory-based study as it requires a range of target frequencies and salience levels. With access to a remarkably large dataset from the mobile application *Airport Scanner*, here we investigated the roles of ITF and salience on visual search performance across 79 different targets that varied in both ITF and salience.

2. Methods

2.1. Overview

All data reported here came from anonymous gameplay data recorded in accordance with the terms and conditions of the standard Apple User Agreement and those provided by Kedlin Co (https://www.airportscannergame.com). Players voluntarily consented to the terms and conditions upon installing the *Airport Scanner* application, and Kedlin Co. made the data available to our research team for analysis. Approval for research use was obtained from the Duke University Institutional Review Board.

Below we provide specific details about the nature of the data, and more information can be found in Mitroff and Biggs (2014). Broadly, *Airport Scanner* is a game wherein the player serves as an airport security officer and reports the presence of illegal items in bags *via* finger taps. The player advances through various levels, which provide a variety of influences (both positive and negative) that can affect search accuracy and efficiency. To simultaneously assess the potential roles of both ITF and salience on search accuracy, we assessed a data pool of 1.1 billion trials. These data were filtered to provide measures of search accuracy, ITF rates, and salience rates; details on the particular filtering done for each measure are provided in Appendix A.

2.2. Participants

Players of *Airport Scanner* advance through various skill levels, from *Trainee* to *Elite*, and we focused all analyses on data from *Elite* players. This provides assurance that the players had sufficient familiarity with the gameplay as they would have had to complete a minimum of 618 trials to obtain this status (and most had significantly more exposure than this). Data were collapsed across players, and no player-specific analyses were conducted.

2.3. Airport scanner gameplay

Players searched for "illegal" target items and identified targets by tapping a finger directly onto the item. Each search display consisted of a single bag that moved from left to right on a conveyor belt, and each bag contained between 0 and 20 items. Items appeared in one of several different bag types that varied in size, shape, and orientation. See Fig. 1 for examples. A bag contained 0, 1, 2, or 3 "illegal" target items and 0 to 20 "legal" items that served as distractors. There were multiple levels (*airports*), which consisted of multiple sessions (*days*), and each session included multiple trials (*individual bags*). Different levels had different time pressures, and some levels became unlocked based upon successful gameplay. Honolulu and Las Vegas were the two earliest levels and had the slowest conveyor belts (*i.e.*, more time can be spent searching per bag), whereas Chicago had a faster conveyor belt, which increased the time pressure, and London and Aspen had the fastest conveyor belts.

Players could obtain in-game upgrades, and while the upgrades performed a variety of functions, they generally made gameplay easier. As such, we eliminated data that were collected when upgrades were active, except for the *Recharge Boosts*, which helped recharge other upgrades for more frequent use (and thus had no effect on a player's in-game performance), and the *Rare Item Magnet*, which attracted certain targets in gameplay that had special value but were not relevant for, or included in, any of the present analyses.

2.4. Target and distractor stimuli

In the data used for this study, "illegal" targets and "legal" distractors included a total pool of 94 illegal items and 94 legal items that could be present during search. Our analyses focused on the target items that could appear in bags alongside legal distractors without requiring special in-game upgrades to view, which provided a pool of 79 possible target items.

2.5. Accuracy trials

Accuracy data were assessed for trials collected between April 15, 2013, and August 26, 2013. Our data filtering for this project (see