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Context matters: The structure of task goals affects accuracy in multiple-target visual search

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ABSTRACT

Career visual searchers such as radiologists and airport security screeners strive to conduct accurate visual searches, but despite extensive training, errors still occur. A key difference between searches in radiology and airport security is the structure of the search task: Radiologists typically scan a certain number of medical images (fixed objective), and airport security screeners typically search X-rays for a specified time period (fixed duration). Might these structural differences affect accuracy? We compared performance on a search task administered either under constraints that approximated radiology or airport security. Some displays contained more than one target because the presence of multiple targets is an established source of errors for career searchers, and accuracy for additional targets tends to be especially sensitive to contextual conditions. Results indicate that participants searching within the fixed objective framework produced more multiple-target search errors; thus, adopting a fixed duration framework could improve accuracy for career searchers.

1. Introduction

Numerous careers require individuals to conduct difficult visual searches; for example, radiologists search medical images for abnormalities, and airport security screeners search luggage for contraband. Accuracy for these tasks is critically important, as any errors could result in fatalities, and career searchers are trained to detect target items with as few errors as possible. Nevertheless, radiologists, airport security screeners, and other highly trained professional searchers still regularly miss targets. As such, a primary goal in applied visual search research is to identify the causes of search errors with the ultimate goal of improving accuracy and performance (Clark et al., 2013).

Visual searches conducted by professionals often present a number of significant complexities. One particular difficulty arises because search arrays can contain more than one target—a medical image could contain multiple abnormalities (e.g., a tumor and a fracture), and a suitcase X-ray could contain multiple banned items (e.g., a water bottle and a gun). Research in academic radiology has investigated the challenges associated with searching for multiple targets and identified a phenomenon known as "satisfaction of search" (SOS; Smith, 1967), the idea that observers tend to be less accurate in detecting a second target after having identified one target in a display (see Berbaum, 2012; for a review). The SOS phenomenon was originally believed to result from an early termination of search, assuming that an observer was "satisfied" with the meaning of the display after the identification of one target and discontinued searching (Tuddenham, 1962). However, further research suggests that this is not the primary cause of SOS because observers do continue to search after detecting one target (e.g., Berbaum et al., 1991). Instead, the decline in second-target accuracy may arise because of attentional disruptions related to the identification of the first target and the depletion of available cognitive resources (Cain and Mitroff, 2012), resulting in faulty decision-making (Berbaum et al., 1998) or faulty pattern recognition (Samuel et al., 1995).

Most investigations of SOS have used radiologists as participants and medical images as stimuli (Berbaum, 2012), but recent experimental work in cognitive psychology has used non-professional participants and precise manipulations of simplified stimuli (e.g., Fleck et al., 2010) to understand the nature of multiple-target visual search more generally (e.g., Cain et al., 2011; Cain and Mitroff, 2012; Fleck et al., 2010). Non-professional participants who search simplified displays demonstrate decrements in second-target accuracy paralleling those seen in radiology, revealing that SOS is a generalizable search phenomenon and not specific to the radiological community. Furthermore, multiple-target search paradigms can be a useful means for investigating the impacts of nuanced cognitive processes; contextual factors such as anticipatory anxiety (Cain et al., 2011) and time pressure (Fleck et al., 2010) can have substantial effects on

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second-target accuracy without altering accuracy for single-target searches.

Exploring how multiple-target search accuracy can be improved is critical because most professional searches occur in settings where multiple targets are possible, and errors can have a tangible and direct impact on health and national security. The goal of the current study is to investigate whether the structure under which searchers complete their tasks can affect accuracy. Both radiologists and airport security screeners conduct series of searches as part of their jobs, but they do so under different constraints: Radiologists typically operate with a *fixed objective* (e.g., assigned to assess 45 mammography images), while airport security screeners are scheduled to search for a *fixed duration* (e.g., scheduled to serve as an X-ray screener at the passenger checkpoint for a 30-min period).

Both radiologists and airport security screeners are trained to maximize accuracy and, in effect, should be attempting the same process—carefully examining each display for potentially harmful targets, regardless of the number of cases yet to be scanned or the amount of time left before the end of a shift. However, it is well known that the conceptual framework of a situation can dramatically alter behavior. For example, a substantially larger proportion of respondents are likely to support a medical program if presented in terms of the proportion of lives saved rather than proportion of lives lost, despite identical results between the conditions (e.g., Tversky and Kahneman, 1981). Given that contextual factors (e.g., anticipatory anxiety and time pressure) can have negative effects on second-target accuracy in a multiple-target visual search (Cain et al., 2011; Fleck et al., 2010), we hypothesized that the framework under which an individual searches could also potentially alter performance. Specifically, we tested whether there are differences in accuracy when a search is completed within a task structure similar to radiology (searching with a fixed objective) versus airport security screening (searching for a fixed duration).

To address this question, we tested non-professional participants using a version of an established multiple-target search task with simplified stimuli that has reliably induced the SOS effect (e.g., Fleck, et al., 2010) and demonstrated sensitivity to environmental contexts (e.g., Cain and Mitroff, 2012; Clark et al., 2011). Professional and non-professional searchers tend to produce comparable patterns of multiple-target errors (Biggs et al., 2013); however, it is important to account for potential differences in motivation between these groups in order to compare their search behavior. Undergraduate research participants may not be as concerned with their accuracy as radiologists and airport security screeners, for whom an error could have fatal consequences. Since assessing goal-relevant performance is only meaningful if individuals are truly attempting to attain the goal (Locke and Latham, 1990; Erez and Zidon, 1984), and monetary incentives offer a simple means to strengthen goal commitment (Locke et al., 1988), we provided a performance-based monetary incentive to increase the likelihood that the participants would genuinely attempt to achieve the instructed task goals. Related work using this motivational structure and the same multiple-target search task found enhanced accuracy in financially motivated versus non-motivated conditions (Clark et al., 2011).

In the current experiment, we compared multiple-target search accuracy among participants searching with a fixed objective versus a fixed duration.[1] Two groups of participants completed an experimental search paradigm in which they accumulated points for accurate searching and were informed that the individual who achieved the "best" performance out of a set of 10 participants would receive an additional $50 in compensation. The paradigm was identical in each of the two conditions except for the framework of the participants' task goal: In the *Fixed Objective* condition, participants were to achieve a specified number of points as quickly as possible; in the *Fixed Duration* condition, participants were to accumulate as many points as possible during a specified number of minutes. For the *Fixed Objective* condition, "best" was defined as the individual who achieved the specified points goal in the shortest number of minutes; for the *Fixed Duration* condition, "best" was defined as the individual who achieved the highest number of points in the specified time period. Importantly, the two conditions were structured such that the optimal strategy in both was identical—to maximize one's rate of point accumulation.

2. Methods

2.1. Participants

Forty undergraduate students were recruited from the Duke University community; 20 were randomly assigned to each condition (*Fixed Objective*: Mean age = 20.15 years (SD = 1.46), 17 female; *Fixed Duration*: Mean age = 19.70 years (SD = 1.34), 13 female). Participants provided informed consent and received $15 for their participation. Each participant had a 10% chance of earning an additional $50—the best performer from each of two consecutively recruited cohorts of 10 participants in each condition received the $50 bonus (i.e., 4 total bonuses were awarded, 2 for each condition). Participants were not informed of their relative performance at the time of testing. After collecting and analyzing data from each set of ten participants, bonus recipients were contacted via email and invited back to the laboratory to collect payment. All other participants were notified via email that they had not received the bonus but thanked for their participation.

2.2. Apparatus

Stimuli were presented on a Dell Inspiron computer with a 20-inch CRT monitor and programmed in MATLAB (The MathWorks, Natick, MA) using the Psychophysics Toolbox (Version 3.0.8, Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). Participants were seated without head restraint at a viewing distance of approximately 57 cm from the screen and completed the experiment individually in a dimly lit room.

2.3. Design

Participants completed a modified version of a multiple-target visual search task that reliably reveals an SOS effect (e.g., Cain and Mitroff, 2012; Cain et al., 2011; Fleck et al., 2010; See Fig. 1). Each trial contained 25 items, consisting of a short bar (0.9° long) and a long bar (1.3° long), each 0.3° wide, which approached one another perpendicularly to form 'T' shapes and pseudo-'L' shapes. Target 'T' shapes were defined as items in which a short bar approached a longer bar at its exact midpoint; the remaining items were considered distractor pseudo-'L's and were defined as items in which the short bar approached the longer bar at any point other than its exact midpoint. The shapes subtended a total area of 1.3° × 1.3° and were presented on a rendered grayscale "cloudy" background with a brightness range of 10–50% black. Distractor pseudo-'L' shapes were always between 28 and 66% black, and target 'T' shapes were presented in two visibility levels: high-salience targets (relatively dark; 66–70% black) and low-salience targets (relatively light; 28–40% black). The high-salience targets were easier to detect and distinguish from the background and

[1] The paradigm employed here is meant to approximate the nature of searches conducted by radiologists and airport security screeners, but key manipulations are necessarily altered. For example, the *Fixed Objective* structure is similar to radiological searches, but true radiological searches use a "Fixed Trials" structure, as immediate accuracy information is not feasible. A "Fixed Trials" condition would have substantially altered the strategy such that speed would be irrelevant.