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Finger and eye-movement foraging strategies employed in feature
and conjunction searches

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Lokaverkefni til BS-gráðu
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HÁSKÓLI ÍSLANDS

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The present paper examines the relationship between the strategies used for the resolution of multiple target visual foraging and target complexity. Research into animal and human foraging behaviour of multiple targets suggests that increasing target complexity increases the attentional load of each target and results in the consecutive selection of homogenous targets, defined as ‘runs’ of target types. This is contrary to the heterogenous selection of available targets that is observed in simple target foraging. The current experiment contrasted feature and conjunction finger and eye-movement foraging of 16 participants. The finger foraging was conducted on an iPad and the eye-movement foraging was conducted with an eye-tracker. The results demonstrated the predicted change from heterogenous target selection to a more homogenous selection of targets in the form of longer and less numerous ‘runs’ of particular target types. The change in foraging strategy was observed in both the finger and eye-movement conditions with longer completion times and over-all movement across the screen associated with the conjunction searches when compared to feature searches. This indicates a stable mechanism underlying the strategies used for foraging of different target complexities akin to problem solving. Individual differences in these mechanisms in particular, or in cognitive capacities in general, mediate the foraging strategies used by participants and lead to certain individuals applying the same heterogenous target selection when confronted with stimuli of increasing complexity with no apparent cost; displaying ‘super-foraging’ abilities.



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Visual foraging is a behaviour observed in both humans and animals. It is characterized by the allocation of attention to relevant features in the visual scene in order to distinguish an item of interest from irrelevant distractors. Examples of visual foraging include picking ripe berries from a bush or pinpointing the coins you just dropped on the street.

Research into animal foraging highlights the role of limited attention using the example of prey detection (Dukas, 2002; Dukas & Ellner, 1993; Emlen, 1966) and distinguishes between optimal strategies that are employed in cryptic versus conspicuous searches (Dukas, 2002; Dukas & Ellner, 1993). The conspicuousness of a given prey determines the attentional allocation associated with prey detection and modulates the rate at which a search is executed (Dukas & Ellner, 1993). According to the model, optimal search efficiency is achieved in conspicuous searches when all prey types are considered targets, and in cryptic searches when only one prey type is focused on (Dukas & Ellner, 1993). According to Dukas (2002) this can be explained by the relative attentional loads of the two searches. In the conspicuous search there is no requirement for fine detail to identify a target and consequently a wide attentional angle is employed, allowing for a large area to be searched per unit of time (Dukas, 2002). In cryptic searches the attentional load is high, given the resolution needed for target identification, resulting in a narrow attentional angle restricting the search to a small area per unit of time (Dukas, 2002). Attentional limitations (Dukas, 2002; Dukas & Ellner, 1993) and the use of internal templates in the form of ‘search images’ (Tinbergen, 1960) lead animals to forage in non-random sequences of homogenous target types or ‘runs’. The observed ‘runs’ are longer than what would be expected by chance (Dawkins, 1971; Kamil & Bond, 2006; Tinbergen, 1960).

Findings on human foraging behaviour point to many of the same conclusions as those concerning animals. Humans studies reveal visual foraging resolutions strategies of longer than chance run lengths (Bond, 1982). This behaviour can be explained through a combination of target priority facilitation, distractor priority inhibition (Brascamp, Blake & Kristjánsson, 2011; Kristjánsson et al., 2013; Nakayama, Maljkovic & Kristjánsson, 2004) and a minimizing of the cost associated with switching between target types (Bond, 1982; Brascamp, Blake & Kristjánsson, 2011; Kristjánsson et al., 2013; Nakayama, Maljkovic & Kristjánsson, 2004). Humans have also been found to engage in patch-leaving; a phenomenon wherein foraging continues until the

frequency of locating individual items of interest drops below the patch average yield rate, after which individuals move on (Wolfe, 2013). Patch-leaving is modulated by circumstantial needs and could be a mechanism behind the foraging of multiple-targets, with each target corresponding to a foraging patch (Wolfe, 2013). This is the case in the current study where two target stimuli must be located amongst two distractor stimuli. Target complexity has been shown to modulate the speed and accuracy with which a participant can switch between target types (Bond, 1982), a finding supported by the feature integration theory of attention (Treisman & Gelade, 1980). The ease with which individuals switch between targets is likely influenced by working memory (Watson & Strayer, 2010) which puts the upper limit on attention span (Baddeley, 1986), and considerable individual differences in attentional ability have been found in exactly this area of cognition (Vogel & Awh, 2008; Watson & Strayer, 2010).

The current study expands upon the findings of Kristjánsson et al. (in press) that dealt with human finger foraging behaviour. The study found evidence that the majority of participants engaged in distinct searching strategies when confronted with multiple target stimuli of increasing complexity (Kristjánsson et al., in press). There was, however, a portion of participants that showed no change in search strategies with no apparent cost to accuracy. These individuals were designated “super-foragers” and examples of such individual differences in cognitive ability have been observed before (Watson & Strayer, 2010). In the following study an additional condition will be added to the Kristjánsson et al. (in press) study; a measure of eye movement foraging behaviour. This was chosen as a comparison in light of the close relationship between saccadic eye movement and visual attention (Kristjánsson, 2011). It is hypothesised that individuals will display the same tendencies to engage in qualitatively distinct searching strategies for both finger and eye movement foraging when confronted with target stimuli of increasing complexity reflecting the increasing demands on attention.

Method

Participants

21 individuals between the ages of 22 and 50 ($M = 26.953$, $SD = 6.499$) participated in the experiment and were recruited by opportunity sampling from Reykjavík, Iceland. There were 15 males and six females. Five participants were not included in the analysis as their data was incomplete and they are excluded from all

subsequent analyses and discussion. All participants reported normal or corrected to normal eye-sight. Two of the participants were left-handed. There were 11 participants that were right handed and had a dominant right eye, four of which had to undergo the eye tracking with lights on due to problems that arose with the eye-tracking. There were three participants that were right-handed and who had a dominant left eye. One participant was left-handed and had a dominant right eye, and the remaining participant was left-handed and had a dominant left eye.

For the finger foraging experiment all participants were naïve to the purpose of the study. For the feature search in the eye movement foraging experiment 11 participants were naïve to the purpose of the study and five were repeating the experiment. For the conjunction search in the eye movement foraging experiment 14 participants were repeating the experiment and 2 participants were naïve.

Apparatus

The stimuli for the finger foraging experiment were displayed on an iPad 2 with a screen dimension of 20 x 15 cm and resolution of 1024 x 768 pixels. The iPad was placed on a table in front of the participants in landscape mode such that the viewing distance was approximately 50 cm. As viewing distance was not rigorously controlled for, distance measures will be reported in pixels. Stimulus presentation and response collection was carried out by a custom iPad application written in objective-C using Xcode and Cocos2d libraries.

For the eye movement foraging experiment the stimuli were displayed on a computer monitor with a screen dimension of 34,3 x 26,1 cm and a resolution of 1024 x 768 pixels. An eye-tracker from Cambridge Research Systems was positioned on the edge of the table at 58,5 cm distance from the screen. Stimulus presentation and response collection was carried out by custom Matlab and Psychtoolbox programs written in C++ and Java.

Stimuli

The target/distractor categories for the feature-based foraging task fell into two stimulus categories. Stimulus category one consisted of red and green circles serving as targets and blue and yellow circles as distractors. Stimulus category two consisted of blue and yellow circles serving as targets and red and green circles as distractors. The target/distractor categories for the conjunction-based foraging task was similarly divided

into two stimulus categories: in stimulus category one the targets consisted of red squares and green circles with red circles and green squares serving as distractors and in stimulus category two the targets consisted of red circles and green squares with red squares and green circles serving as distractors. All stimulus items appeared an equal number of times distributed randomly across a black background and adjusted through a random offset added in both vertical and horizontal directions to generate a heterogeneous appearance.

For the finger foraging experiment there was a total of 40 targets. All stimuli had a diameter of 20 pixels and were distributed across a 10 x 8 grid offset from the edges of the screen by 150 x 100 pixels with the viewing area occupying 15 x 12. Minimum gaps between stimuli ensured no occlusion or overlap of stimuli.

For the eye movement foraging experiment there was a total of 16 targets. All stimuli had a diameter of 1° degree visual angle and were distributed across a 6 x 6 grid offset from the edges of the screen by 100 pixels. The region of interest that resulted in selection of the target was scaled to four, such that the target zone was triple the size of the target stimulus. The region of interest around the distractors was equal to the size of the distractors. The fixation time required for selection was 100 ms and the minimum distance between stimuli was 2,5° degrees visual angle to ensure no occlusion or overlap of the stimuli.

Design

The experiment followed a within-participant design with a counterbalanced order of the feature and conjunction search tasks as well as for the eye movement and finger foraging conditions. The stimulus category in each of the search types were consistently paired within participants and across foraging conditions although they were randomized and counterbalanced between participants. The independent variables were the foraging conditions – eye movement and finger foraging – and search types – feature and conjunction. The dependent variables were the number of runs – i.e. the number of times participants switched between stimulus category during the course of one trial, completion time, total movement length measured in pixels, and the error count.

Procedure

The experiment was conducted in a sound-proof room. Participants were asked to complete the tasks as quickly and accurately as possible by selecting the targets and

avoiding the distractors. No instructions were given regarding the method of selecting the targets. Both search tasks within the two foraging conditions included initial practice trials followed by 20 experimental trials. Each trial required participants to empty the display of all target items and avoid all the distractor stimuli. After completing the trial a message conveying successful completion appeared on the screen followed by the subsequent trial. In the case of a selection of a distractor an error message appeared and the previous trial was restarted.

The finger foraging search tasks took place under conditions of standard illumination. Participants were given 5 practice trials followed by 20 experimental trials in both the feature and conjunction tasks. The success message appeared with the number of the trial and the amount of time in which the trial was completed such that participants were able to inform the researcher once the 25th trial was concluded and the next finger foraging task was commenced.

The standard conditions for the eye movement foraging task consisted of no lighting apart from that which came from the computer monitors. Three participants required lighting due to enlarged pupils which impeded eye-tracking. Participants were first calibrated to the eye-tracker (only the dominant eye) and given 10 practice trials followed by the experimental trials in both the feature and conjunction tasks. Success and error messages instructed participants to press the space key to continue. After completion of all the trials the program automatically ended the search session and the next search task commenced.

Results

All outliers were removed from the data collection following the \pm three standard deviations rule prior to data analysis. In the eye movement foraging condition all instances in which only 1 or no stimulus were looked at before the occurrence of the error were removed from the total participant error count. The reason for this was a lack of fixation point such that a participant could happen upon a distractor as soon as the stimuli appeared on the screen. The 1 stimulus then error rule was used as participants could be fixating the location of a stimulus as it appeared on the display and immediately shift their gaze to a distractor if they were not fully prepared and resisting the urge to saccade to salient features. Comparison of search types, i.e. feature vs.

conjunction, within each of the foraging conditions, i.e. finger vs. eye movement, is addressed first; followed by a contrast of foraging conditions.

Finger foraging

Figure 1 depicts the average run length on the y-axis, as measured by the number of consecutive target stimuli of one type, against the trial number on the x-axis for the feature and the conjunction searches of all participants. There is a trend of conjunction searches showing a high average run length and feature searches showing a very low average run length. There are four subjects that have consistently low run lengths for both search conditions, and those are observers 4, 6, 12 and 14. The run lengths refer to the number of consecutively chosen stimuli of a given type, i.e. of a given colour or a given shape and colour. Observers 8 and 15 fall somewhere in between; with observer 8 tending towards a lower average run length in the conjunction condition, and observer 15 alternating between slightly lower conjunction run lengths and higher feature run lengths.

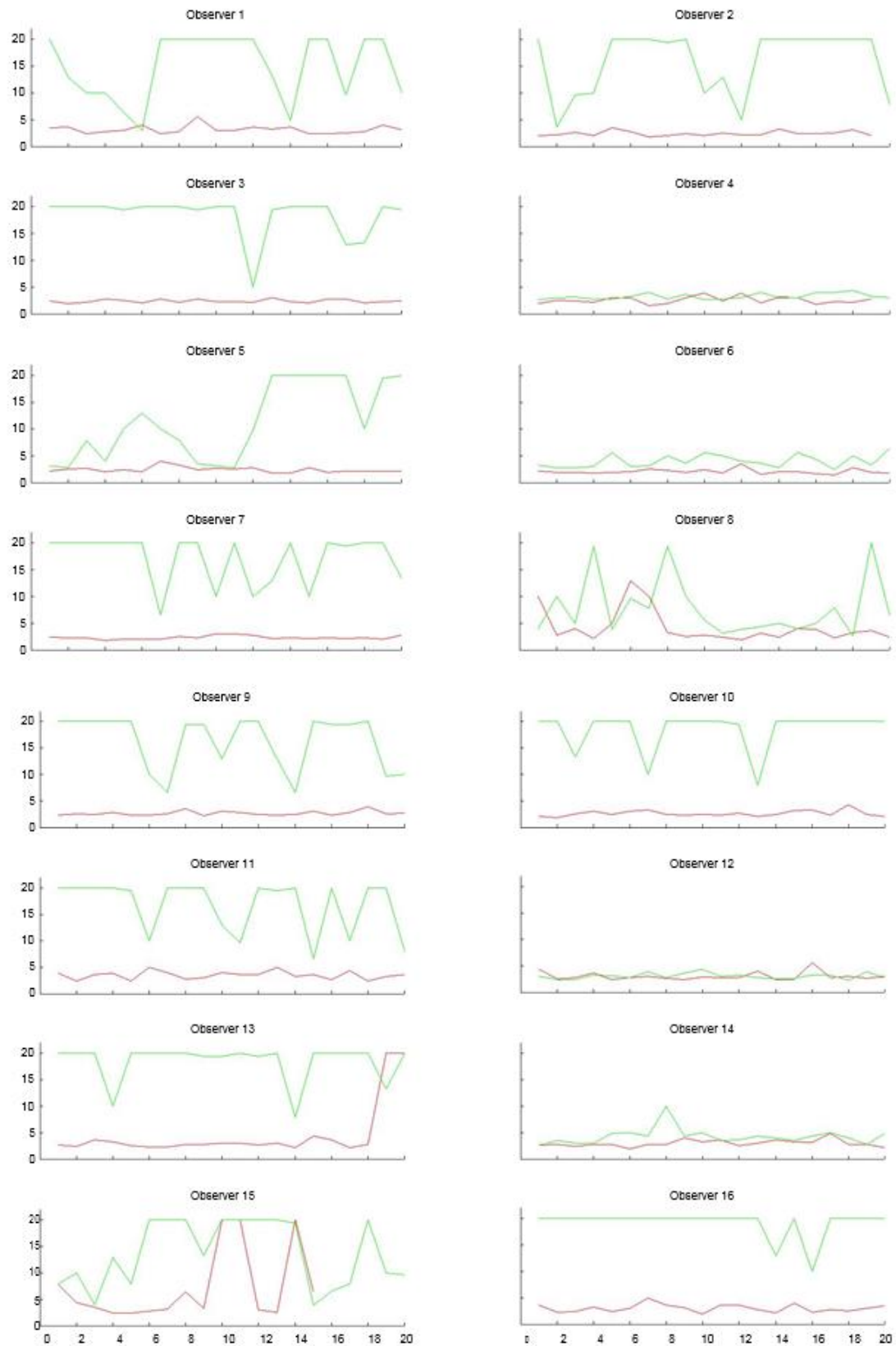


Figure 1. Average run length, y-axis, as a function of trial number, x-axis, for each participant in both the feature (in red) and conjunction (in green) finger foraging conditions.

Figure 2 depicts the path plots of two randomly chosen trials, one for each search condition, from two randomly chosen participants. The plots depict the order in which participants chose the stimuli and the path they took from the first to the last, indicating the different target stimulus types with different colours. The stimulus types themselves are not of interest, rather the behaviour of switching between them and the length of runs that characterize each search condition. The number of runs in each of the trials is noted at the top of each path plot and there is a clear difference between the feature and the conjunction condition. In the feature searches both participants engage in a strategy consisting of clearing the display screen in one go with little cross-over or doubling back of the path line and little regard for the type of the target stimulus in question. The conjunction conditions show two very different pictures. The top right plot depicts quite a bit of switching between stimulus types and the participant exhausts one of the target stimuli before moving onto the next in any given area, resolving the total display screen in segments. The bottom conjunction path plot shows an example in which the participant attempts to exhaust the total display screen of all the available target stimuli of a single type before moving on to the other target stimulus with one exception, resulting in much more cross-over of the path lines and an increase in the total movement length.

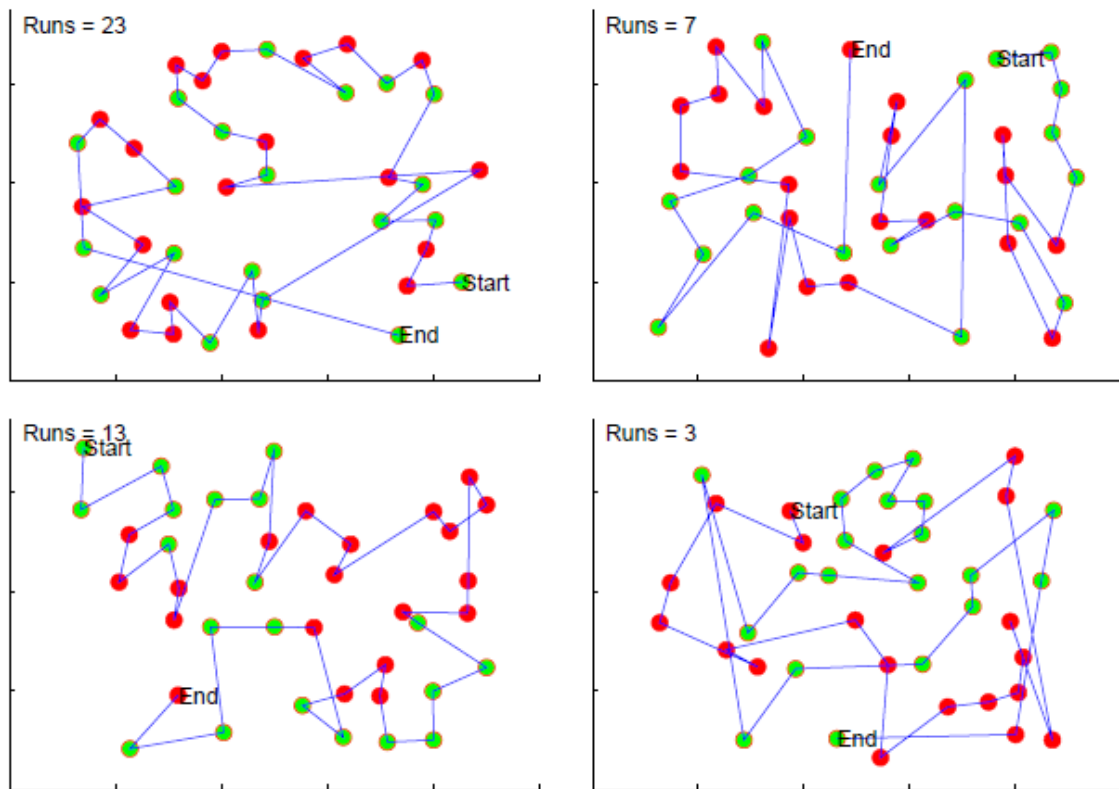


Figure 2. Subject path plot depicting the chosen stimuli order from two randomly chosen trials from two randomly chosen participants in the feature (left) and conjunction (right) finger foraging conditions displaying the run number for the trial.

In the finger foraging search conditions, one participant (15) stood out for deviant performance. The participant's performance qualified as an outlier in the feature search and the error count was almost three times as high as that of the next highest participant. The participant in question also only completed 15 of the required 20 trials in the feature search, had the lowest average completion time, which potentially contributed to the high error count, and had an average movement length that was over three standard deviations longer than the mean. The participant also had the lowest number of runs of the sample in the feature condition as well as the greatest movement length and second highest number of errors in the conjunction condition. Another participant stood out for unusual behaviour but only in the conjunction search, participant number 12. This participant had the highest error count (closely followed by participant 15) the highest completion time and run number and the lowest movement length. For participant 12 the very high error count and completion time may be explained by the unusually low movement length and high number of runs. The two

participants are mentioned here as the former exerts a clear influence on many aspects of the subsequent data analysis, and the latter should to be kept in mind for the influence exerted on the conjunction search distribution – and the subsequent use of non-parametric significance tests that are used for statistical analysis.

In the feature search the error count showed a strong and significant correlation with movement length, $r = 0.797$, $p < 0.001$, although this was strongly influenced by participant 15. Participants engaged in a significantly lower than random average run number ($M = 14.467$), $t(15) = -8.903$, two-tailed $p < 0.001$, and the average movement length and number of runs showed a moderate and significant negative correlation, $r = -0.629$, $p < 0.001$, again this was strongly influenced by participant 15. There was no significant relationship to be found with average feature completion times.

The conjunction search showed a moderate and significant positive correlation between the error count and both the run number, $r = 0.656$, $p = 0.006$, and the completion time, $r = 0.639$, $p = 0.008$. Participants engaged in significantly fewer than random average run numbers (*Median* = 3.354) as measured by the one-sample Wilcoxon signed-ranks test at the $p < 0.001$ significance level. The non-parametric test was chosen given the significantly non-normal distribution of the number of runs, $K.S.(16) = 0.144$, $p = 0.001$. The run number showed a strong and significant negative correlation with movement length, $r = -0.792$, $p < 0.001$, and a strong and significant positive correlation with completion time, $r = 0.758$, $p < 0.001$. A moderate and significant negative correlation was found between completion time and average movement length, $r = -0.660$, $p = 0.005$.

There was no significant difference in the error count between the feature (*Median* = 5.50) and conjunction (*Median* = 7.50) searches as assessed by the related-samples Wilcoxon Signed-ranks test. The non-parametric test was used as the feature error count showed a significantly non-normal distribution, $K.S.(16) = 0.220$, $p = 0.038$. A related-samples Wilcoxon signed-ranks test revealed the average number of runs to be significantly higher in the feature search (*Median* = 14.275) than in the conjunction search (*Median* = 3.354) at $p < 0.001$, as mentioned above the conjunction run length distribution was significantly non-normal and therefore a non-parametric significance test was chosen. There was no significant correlation found between the run numbers in the two search conditions. Movement length for the feature search showed a non-normal distribution, $K.S.(16) = 0.278$, $p = 0.02$, therefore the related-samples Wilcoxon signed-

ranks test was used to compare the two conditions. The conjunction search showed a significantly higher average (*Median* = 158.117 pixels) than the feature search (*Median* = 128.383 pixels) at the $p = 0.001$ significance level. There was also a moderate and significant positive correlation found between the movement length, $r = 0.597$, $p = 0.015$ between the search types. Average completion time was found to be significantly longer in the conjunction search ($M = 18.789$ seconds) than it was in the feature search ($M = 13.484$ seconds), $t(15) = 6.528$, two-tailed $p < 0.001$. The completion times for the feature and conjunction search conditions were moderately and significantly positively correlated, $r = 0.535$, $p = 0.03$.

Eye Movement foraging

Figure 3 depicts the participant feature and conjunction eye movement search average run length per trial, as seen in the finger foraging above. The pattern here is more variable compared to the finger foraging but the trend remains that the conjunction searches have longer runs. The most striking pattern is that of observer 10 who has an almost identical average run length for the two search conditions. Observer 12 shows a similar pattern between the two searches, as does observer 6, however the other participants tend to demonstrate a systematic increase in conjunction run lengths although the amount of this increase fluctuates.

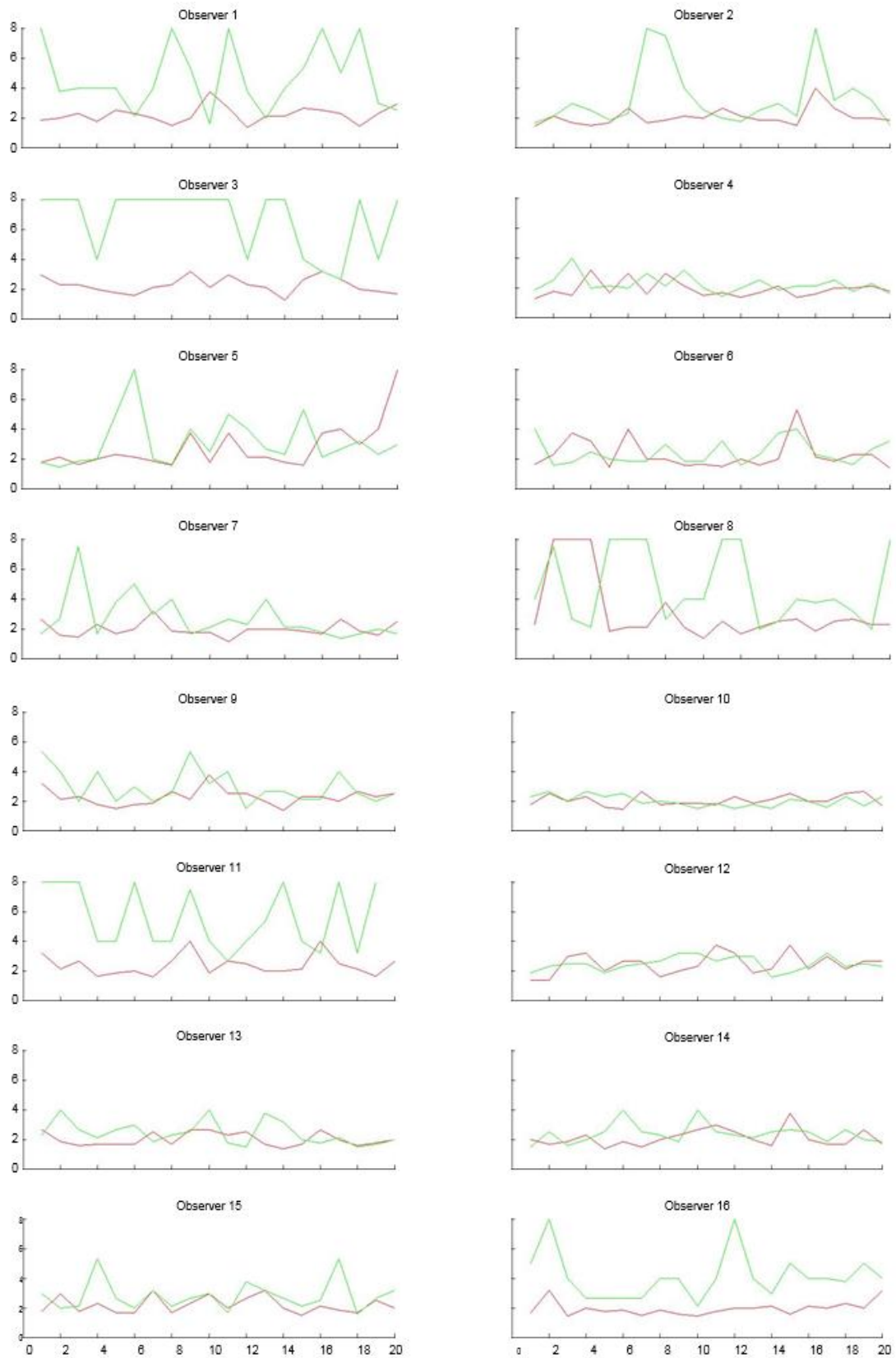


Figure 3. Average run length, y-axis, as a function of trial number, x-axis, for each participant in both the feature (in red) and conjunction (in green) eye movement foraging conditions.

Figure 4 depicts the path plots of two randomly chosen trials, one each of each search condition, from two randomly chosen participants. The difference is not as large as that which was observed in the finger foraging path plots, however there is a systematic decrease in the number of runs between the feature and conjunction searches, as seen also in figure 3.

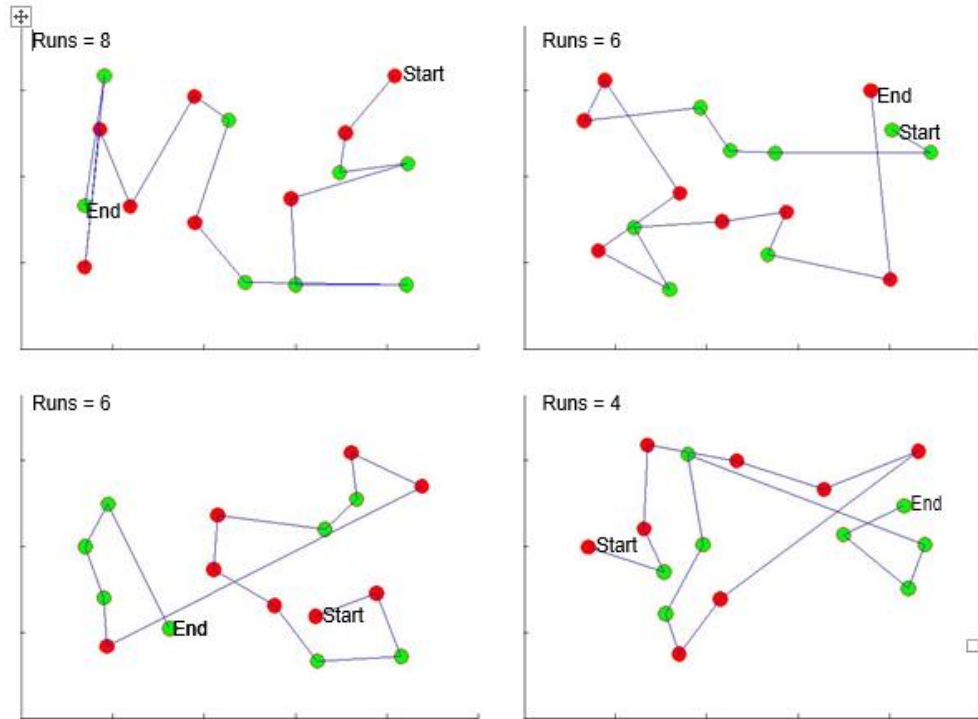


Figure 4. Subject path plot depicting the chosen stimuli order from two randomly chosen trials from two randomly chosen participants in the feature (left) and conjunction (right) eye movement foraging conditions displaying the run number for the trial.

In the feature search there was no significant correlation found between error counts and the other variables. The average number of runs ($M = 7.519$) was found to be significantly different from chance, $t(15) = -2.958$, two-tailed $p = 0.009$. There was no significant correlation between the number of runs and movement length or completion time, nor was there a significant correlation between completion time and movement length.

In the conjunction search the correlation between error count and other dependent measures was not significant. The number of runs showed a significantly non-normal distribution, $K.S.(16) = 0.222$, $p = 0.035$, and so the one-sample Wilcoxon

signed-ranks test was applied and revealed the average number of runs (*Median* = 6.05) to be significantly lower than random at the $p < 0.001$ significance level. The number of runs showed a moderate and significant negative correlation with movement length, $r = -0.502$, $p = 0.048$, but no significant correlation was found between the number of runs and the completion time, nor between the completion time and average movement length.

A related-samples Wilcoxon signed-ranks test showed a significantly higher error count in the conjunction condition (*Median* = 29) when compared with the feature condition (*Median* = 3) at $p < 0.001$ significance level, although the two were not significantly correlated. The non-parametric test was used because of a significantly non-normal feature error count distribution, $K.S.(16) = 0.223$, $p = 0.033$. A related-samples Wilcoxon signed-ranks test revealed a significantly lower number of runs in the conjunction search (*Median* = 6.05) compared to the feature search (*Median* = 7.575) at the $p = 0.001$ significance level, and this also showed a moderate and positive correlation that approached significance, $r = 0.440$, $p = 0.088$. Average movement length showed a moderate and significant correlation between the two conditions, $r = 0.595$, $p = 0.015$, and was significantly greater in the conjunction ($M = 211.335$ pixels) when compared to the feature search ($M = 188.089$ pixels), $t(15) = 4.497$, two-tailed $p < 0.001$. Finally, average completion times were significantly longer in the conjunction search ($M = 11.510$) than in the feature search ($M = 7.834$), $t(15) = 6.632$, two-tailed $p < 0.001$.

Eye and Finger foraging contrast

The error count in the finger foraging feature search was moderately and significantly positively correlated with the movement length in the eye movement foraging conjunction search, $r = 0.517$, $p = 0.040$, although this appears to be largely due to the influence of participant 15. There was a moderate negative correlation between finger foraging conjunction movement length and eye movement foraging conjunction error count that approached significance, $r = -0.491$, $p = 0.053$. Finger foraging conjunction movement length showed a moderate and significant positive correlation with eye movement foraging conjunction movement length, $r = 0.553$, $p = 0.026$. Eye movement foraging feature completion time showed a moderate and significant positive correlation with finger foraging conjunction completion time, $r = 0.547$, $p = 0.028$, but not with finger foraging feature completion time, but this appears strongly influenced by

participants 15 and 12. The above correlations retain their significance after application of the Bonferroni correction to the alpha values. Finger foraging feature completion time showed a moderate and negative correlation with eye movement foraging conjunction number of runs that approached significance, $r = -0.447$, $p = 0.082$. Eye movement foraging conjunction completion time did not show even remotely significant correlations with either of the finger foraging search completion times.

Discussion

Human foraging is a behaviour that is modulated by the specifications of the task at hand. In the current experiment a within-participants comparison was made between feature and conjunction conditions in finger foraging and eye movement foraging following the general design of Kristjánsson et al.'s (in press) study. The present study provides results that support the hypothesised employment of qualitatively distinct search strategies, in both finger and eye movement foraging, for the feature and conjunction search conditions.

The results were clearest in the finger foraging experiment. Firstly, there was no significant difference between the error counts in the search conditions demonstrating that there was no systematic change in participants' ability to conduct the different searches accurately. There was a significantly lower than random average number of runs, the amount of switching between target types, indicating a strategic approach to foraging in both search conditions. This can be explained by a facilitation within runs (Bond, 1982; Dawkins, 1971; Kristjánsson et al., 2013) account, a responsiveness to the relative abundance of stimuli (Dawkins, 1971; Emlen, 1966; Hills, Kalff & Wiener, 2013; Kamil & Bond, 2006; Tinbergen, 1960; Wolfe, 2013) account, or both. There was also a significantly lower average number of runs, longer completion times and longer average movement length in the conjunction search as compared to the feature search. Taken together, this demonstrates that participants decreased the amount of switching between targets even though it involved a cost in the time it took to complete trials and an increase in the total amount of movement made across the screen. An increase in attentional load given the requirement of integration of features (Treisman & Gelade, 1980) is seen from the above results in the conjunction search and this also supports the model in which there is an increase in selectivity given an increase in prey crypticity (Dukas, 2002; Dukas & Ellner, 1993), where prey crypticity is substituted by target

complexity. A correlation between feature and conjunction completion times and movement lengths indicates that participants took a proportionately greater amount of time to process and respond to targets in the conjunction condition as well as employing distinct resolution strategies that require more movement across the screen. This is presumably to avoid the cognitive cost associated with frequent switching between targets (Bond, 1982; Kristjánsson et al., 2013), just as was observed in the Kristjánsson et al. (2013) study. Further evidence supporting this conclusion derives from the correlations that were found in the conjunction search between the error count and both completion time and the number of runs. This demonstrates that participants committed more errors when engaging in a greater amount of switching between target stimuli and when resolving the searches in a shorter amount of time. There was also a correlation found between the conjunction completion times and the number of runs, demonstrating that an increase in switching between targets was indeed associated with a greater cognitive cost. This is further supported by the negative correlation found between the completion time and movement length.

There were two super-foragers found in the current experiment for the finger foraging condition, observers 4 and 14. Two other participants, observer 6 and observer 12, appeared to meet the criteria of super-foragers for the finger foraging but the error counts showed a four-fold and seven-fold increase respectively. This clearly violates the premise of no cost associated with switching behaviour when confronted with more complicated stimuli. The eye movement foraging condition showed a few potential super-foragers but the increase in error counts, ranging from a four-fold to 20-fold increase, clearly ruled this out. The lack of super-foragers in the eye movement foraging may have been attributable to the short time that was required for a stimulus to be selected, although this in itself is indicative of the increased time that is required for the integration of features (Treisman & Gelade, 1980) in the conjunction condition. The lack of super-foragers in the eye movement foraging search may call into question the legitimacy of the two super-foragers that were found in the finger foraging search. Further research is needed to determine the generalizability of super-foraging behaviour and the conditions under which it is observed.

The eye movement foraging data showed over-all similar results as the finger foraging data, although the trends were not as clear. There was a significantly higher average error count in the conjunction search than there was in the feature search,

indicating that there was a systematic decrease in participants' ability to resolve the searches with increasing target complexity. This might reflect the conditions of the eye movement foraging experiment; participants had a maximum fixation time after which the stimulus that was being foveated was selected, allowing less time for feature integration and limiting decision times. The number of runs in the two search conditions was, again, lower than the random run average, demonstrating a strategic approach to the resolution of the display which supports either a facilitation account (Bond, 1982; Dawkins, 1971; Kristjánsson et al., 2013) or a responsiveness to the relative abundance of the stimuli (Dawkins, 1971; Emlen, 1966; Hills, Klaff & Wiener 2013; Kamil & Bond 2006; Tinbergen, 1960; Wolfe, 2013) account, or both. There was a significant negative correlation between the run number and movement length in the conjunction search, although no such correlation was found in the feature search. The number of runs was significantly lower, and the movement length and completion times were significantly longer in the conjunction search when compared to the feature search. This reproduces what was seen in the finger foraging, and holds the same implications; namely, that participants decreased the amount of switching between targets which entailed a cost in time and movement across the screen. This demonstrates that the two searches involve different strategies supporting an account of increased selectivity with increases in attentional load (Dukas, 2002; Dukas & Ellner, 1993) given by increased target complexity.

The decrease of clarity that is seen in the results for the eye movement foraging may be explained by an increase in measurement error or by a disproportionate increase in design difficulty. Participants in the experiment commented on the inaccuracies that they felt in the selection of targets and distractors in the eye movement foraging condition, and said comments were largely directed at the conjunction search. This could reflect the increase in error rate associated with the conjunction condition and to participants not accounting for the increase in decision time associated with the integration of features required for target identification, thus resulting in their passing over distractors too slowly. Some of this could also have been due to calibration inaccuracies.

Perhaps the most important result for the present purpose is the comparison between the eye and finger foraging. These show a consistency across the foraging conditions. First, there was a significant correlation found between the conjunction

movement lengths in the finger and eye movement foraging conditions. This indicates a consistency of resolution strategies employed in the foraging tasks that carries across measurement tools. The above is important given the lack of clarity in the results of the eye movement foraging experiment. The consistency suggests that both measurements are sampling a stable trait that can be likened to a type of problem solving; that of choosing the most efficient strategy for locating multiple targets amongst distractors. A significant negative correlation was found between finger conjunction movement length and eye conjunction error rate, such that individuals that moved across the screen more in the finger foraging committed fewer errors in the eye movement foraging. This relationship was also observed within the finger foraging conditions, which were likely subject to less measurement error, and seeing it transfer across counterbalanced foraging conditions further substantiates the inference of stable foraging strategies. The final significant correlation that was found between the eye movement and finger foraging was a negative correlation between finger feature completion time and eye movement conjunction run numbers. This demonstrates that participants that are faster in the feature condition also show a decreased number of runs in the conjunction conditions. The finding could be indirectly related to a general foraging search efficiency such that longer runs in the conjunction condition were related to more successful and efficient searches in the finger foraging condition.

Further investigation into visual foraging is needed but the results suggest interesting implications for general and stable mechanisms, as well as specific individual differences. Currently there is a need for norm formation of more specified populations, as the sample in question was in no way representative of the general population given that most of the participants were of university age. There is also a need to clarify the mechanisms that are functioning behind the observed foraging runs. Potential explanations include priming resulting in a decrease in response time with each consecutive target stimulus of the same type, or prior stimuli influencing the choice of the subsequent targets (Brascamp, Blake & Kristjánsson, 2011). Search strategies could reflect patch leaving (Wolfe, 2013), target abundance (Dukas, 2002; Dukas & Ellner, 1993; Emlen, 1966), minimizing the cognitive cost of changing between ‘search images’ (Tinbergen, 1960) or some combination of the above. An improvement in the eye movement foraging design should be attempted as the error count was far too high and

participants consistently provided feedback concerning the inaccuracy of the eye movement conjunction search condition.

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