Abstract

When we engage in visual search, three factors vie for attentional control: top-down tuning, bottom-up feature contrast, and history effects (Awh et al., 2012). This study focuses on isolating the role of top-down tuning, a process by which attention is guided based on the goals of the individual (Folk & Remington, 1998), from the potentially confounding effects of bottom-up feature contrast and target related history effects. We seek to fill gaps in literature by proposing an analogue to the 'Eureka' effect as seen in memory research (Auble et al., 1979). This 'Eureka' effect, we propose, would allow individuals to attend to a feature based solely on verbal instruction, thus being motivated entirely through top-down tuning. The current study aimed to investigate this by providing verbal instruction that would assist in completion of a particularly difficult search during the course of their task. They were not made aware of this critical information prior, thus had no reason to attend and gain history with the target. We investigated participants search performance through response accuracy and eye tracking measures. Crucially, participants were not given task feedback. Our results showed that participants become more accurate as time with the task increased while eye movement measures decreased, showing potential deployment of covert attention. The critical trial in which top-down tuning was theoretically the only motivating factor of attention was not different from trials with similar amounts of history effects. These findings imply that verbal top-down tuning in this form is not sufficient to drive attention. This may be due to lack of motivation to adapt search strategies and incorporate new top-down information. Additionally, evidence was found to suggest history effects can survive interleaving of irrelevant trials.

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The Influence of Verbal Guidance on Visual Search: Isolating Top-Down Tuning from Target History Effects

Visual search is the process by which attention is directed towards either 'targets' or 'distractors' within a task environment (Treisman & Gelade, 1980). It is generally agreed upon that this attention can be guided by one system and two overarching effects, the: top-down tuning system, bottom-up feature contrast effect, and history effects (Awh et al., 2012). Top-down tuning is the ability to exert control over attention and direct it to task-relevant stimuli (Folk & Remington, 1998; Folk et al., 1992; Luck et al., 2021). For example, if we are looking for our red car in a crowded parking lot, we only select red items in our search. Bottom-up feature contrast is the process by which attention is automatically attracted to or 'captured' by physically salient stimuli with the highest feature contrast even if these stimuli are completely unrelated to the task or goal (Theeuwes, 1994; Theeuwes et al., 2006). For example, wearing an orange vest in a forest involuntarily attracts attention more than wearing military camouflage; one has high feature contrast, the other low. Finally, history effects, including implicit learning effects and priming effects, can bias attention towards features that are similar in items that have already been selected during a task, with this process biased towards targets as compared to distractors (Maljkovic & Nakayama, 1994).

The central question of this thesis is "*Can verbal instruction alone guide attention?*". This might seem perplexing, considering this question appears to be both self-evident from everyday life and addressed quite thoroughly within the literature (Folk & Remington, 1998; Folk & Remington, 1996; Folk et al., 1992; Luck et al., 2021). However, previous investigations have failed to pry apart top-down tuning from history effects. The main issue with these previous investigations is that history effects are difficult to eliminate or reduce in methodology. For example, if a task requires participants to select an item in a display, they are shown this item beforehand. Typically, participants are required to complete a task repeatedly over many trials, which are subsequently averaged together. The same target is therefore selected over and over again. The question then arises: Does the visual system need sensory input and experience with selecting a target to tune attention to the target? This contamination of effects in the literature is what we hope to address here through the use of a novel paradigm and investigation into a 'Eureka' type effect.

Eureka

The 'Eureka' effect commonly describes the moment where we become cognisant of the solution to a problem despite not actively working on the task in a traditional sense. The classical example is that of the Greek philosopher Archimedes and his bathtub. Upon lowering himself into a drawn bath, he had a flash of insight that the displaced water would be an exact measurement of the volume of his body. These sudden 'Eureka' moments do not rely on logic or a painstaking process of reasoning, but rather comes out of mundanity. Modern memory research into these moments of clarity have found its appearance in many types of problem-solving scenarios (Auble et al., 1979; Hutchinson, 2014; Wills et al., 2000) and even in primates (Köhler, 1973). The prerequisite for a 'Eureka' effect is that information required to perform the task optimally is always available (Metcalfe, 1986), yet needs to be processed in a particular (conscious) manner to achieve optimal performance. A classic example in the domain of perception of this effect can be found in certain 'optical illusions'. Before reading the note of Figure 1, try to reason what the subject of the photograph is. Upon reading that caption, perception becomes shaped purely by semantic information, with this information become difficult to 'unsee'.

Figure 1.

'Optical illusion'

Note. The subject is most often not clear on first viewing. The initial perception of the image becomes difficult to replicate once perceiving the true subject of the photograph, a dalmatian dog named 'Woody' in the snow ("Critical Turn In Vietnam," 1965).

An effect such as this has yet to be proposed in visual search. More to the point, it hasn't been shown to exist in attention, so it is unclear whether it could guide attention at all. We would except this effect to work similarly to its memory counterpart, where upon having this "A-ha!" moment; participants would be able to 'solve' their problem, in this case selecting a target in a visual search-style task. These moments could potentially contain history effects, as the critical information is always available, however, this wouldn't lead to the same level of performance in the task (Becker et al., 2009).

History effects

History effects subsume a range of effects such as implicit learning, statistical learning, training effects, and intertrial priming (Becker et al., 2009; Duncan & Humphreys, 1992; Duncan & Humphreys, 1989; Thorat et al., 2022). These effects are automatic in nature; participants cannot help but engage with these processes (Goujon et al., 2015). For example, intertrial effects describe the phenomenon that selecting a target stimulus biases or primes participants to attend to the same feature on subsequent trials (Maljkovic & Nakayama, 1994). Yantis and Jonides (1984) showed that the abrupt onset of a novel stimuli captured attention despite participants knowing it gave unreliable task target information (although they did follow-up and show top-down tuning could supersede this response in some cases (Yantis & Jonides, 1990)). These priming effects have also been shown to facilitate search when the stimulus features of both target and non-targets are repeated and to produce switch costs when the features change or swap (Kristjánsson & Driver, 2008; Kristjánsson et al., 2002; Maljkovic & Nakayama, 1994). These effects can also be cumulative, building gradually over time. We also know that participants can be trained in visual search tasks and can become markedly better at them simply through repetition (Zhang et al., 2022). For example, over time stimulus-to-response mappings can be learnt and become automatic over time (Schneider & Shiffrin, 1977).

Statistical learning is the unconscious ability of the visual attention system to pick up on patterns, regularities, and consistencies in a task (Frost et al., 2019). These processes are proposed to play an important role in the guidance of visual attention (Chun & Jiang, 1998; Gibson & Jiang, 2001) and theoretically our ‘Eureka’ effect. The effect is most often demonstrated in the *contextual cueing paradigm* (Chun & Jiang, 1998), where participants engage in a difficult search task (e.g. looking for a T among L’s) and show progressively shorter response times towards repeated search displays that are occasionally presented, interleave with non-repeated (new) displays. The contextual cueing effect shows that participants can easily learn regularities in the positioning of the target. It is important to note that this effect is implicit: participants are unable to distinguish the repeated displays from completely new displays in a later memory task; whatever knowledge they acquired during the task is not conscious. Many tasks in the visual search literature around top-down tuning involve repeated tasks in which participants might have a chance of unconsciously employing statistical learning. It is therefore clear that a new methodological approach is required to prise apart this effect from top-down tuning.

These are the type of effects that may very well clutter our current understanding of how top-down tuning may function in visual attention as they masquerade as top-down tuning (Becker et al., 2009).

Top-down Tuning

Many researchers have, for many years, performed experiments and wrote papers on the nature, relationship, and impact top-down tuning has on attention. Using a variety of methodologies, researchers have tested a range of hypotheses related to top-down tuning. For example, according to the *contingent capture hypothesis*, attention is guided by a top-down target template via *attentional control settings* (Folk et al., 1992). A target template is an internal representation of an object or feature that is being search for. When visual search is engaged, the target template is held in working memory to help guide attention towards relevant stimuli. The attentional control settings are the criteria upon which attention is allocated based on task demands. These configurations are contingent on the goals of the individual and can guide attention to be captured even if non-targets are equally salient as targets. This allows top-down tuning to dominate over bottom-up feature contrast in situations where features are not shared between target and non-target (Bacon & Egeth, 1994).

Issues arise however when we try to think of the top-down tuning being investigated being separate from history effects. Very often the tasks asked of participants require that they identify a target in a field that they become familiar with through the task, knowing that it is that target that they must find and attend to. For example, a study by Folk and Remington (1998), participants are subjected to four experiments all designed around attending to a target with a unique colour, a colour singleton (Folk & Remington, 1998). Participants were given an instruction, engaged with practice trials, and the results reported through the average performance over all trials. What is missed in the explanation of their results is an account for learning and history effects. Credit is given to the instruction while it has previously been shown that history effects can impact performance in this type of paradigm. Participants are engaging with a learning effect to select their target rather than having their attention tuned solely by their top-down control settings (Duncan & Humphreys, 1989). Meaning that the only true top-down tuned attention trial is the first trial after receiving instructions. A possible Eureka effect could confirm that top-down tuning in its purest form is possible.

The Present Study

As mentioned above, adequate investigation into top-down tuning in response to purely verbal instruction is missing. As such, the present study aims to assess if and to what extent verbal instruction allows efficient top-down tuning of attention during visual search. By utilising a novel paradigm that allows for measuring potential Eureka effects of attention while accounting for history effects in critical trials, the present study centrally aims to investigate if and to what extent an analogue for the well-known “Eureka” effect exists in visual search tasks.

In the experiment, participants will be presented with two types of trials: search trials (75% of all trials) and randomly interleaved probe trials (25% of all trials). The critically important trials are the probe trials, wherein participants will be instructed to identify a number that is presented among three letters in a four-item array. This array is visible only briefly (367 ms), after which all items will be backward masked. The number and letters are presented against the background of four differently coloured disks. The search trials are designed to keep participant attention, minimise history effects by attempting to clutter visual working memory, and to obscure the portion of the probe trials that pertains to the yet-to-be-given semantic instruction. Unbeknownst to the participant, the target number in the probe trials is always presented against the background of a pre-selected colour (e.g. blue). Approximately half-way through the experiment, participants will be provided this information and asked to use it to better attend to the number. During this break they will also be questioned as to if they had noticed this prior. If they did, they were excluded. Regardless the experiment continued to completion. This allows the paradigm to exclude those whose performance may be impacted by history effects.

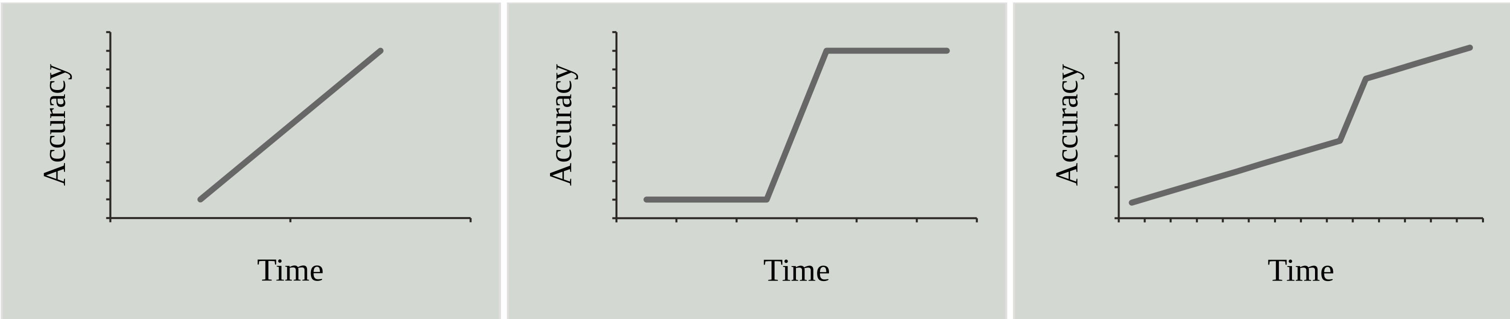
It was found during pilot experimentation that the requirement to constantly associate the target with an attribute that can guide attention (e.g. colour, motion), while preventing participants from noticing the association presented a problem. Many stimuli sets were born and lost to floor and ceiling effects. The current paradigm uses the short presentation time in an attempt to slide into the gap between the inability to register patterns and the ability of the target template to guide attention.

To analyse these data, firstly, two-tailed paired samples t-tests and linear regressions will be used to compare pre- and post-instruction trials within participants. Both a hypothesised Eureka effect and history effects would predict that participant accuracy in the probe trials will be significantly higher in the post-instruction trials as compared to the pre-instruction trials. Statistical learning effects and other history effects should lead to a gradual increase in accuracy with trial number (Maljkovic & Nakayama, 1994), so that accuracy should increase approximately linearly with trial number. We will also perform t-tests concerting the first semantic information trial to see if there is a marked difference between that trial and the trials surrounding it, both pre- and post-instruction. A Eureka effect should lead to a single large increase in accuracy in the probe trial directly following the instructions, compared to the previous probe trial (prior to instruction).

Secondly, to examine whether statistical learning / history effects and / or Eureka effects can affect probe trial performance at an early stage of visual attention, prior to selecting the relevant items, we will examine the eye movements of participants during the probe trials. Eye movements allow for measurement of early processes of visual selection more directly, as they occur earlier than a manual response and provide a more fine-grained measure of how attention was allocated to the different items in the display (e.g., Hamblin-Frohman & Becker, 2021; Ramgir & Lamy, 2022; Zelinsky et al., 1997). The first eye movements in a trial regarded as an especially good indicator of covert attention shifts, as they are not contaminated by later processes (e.g., object identification, distractor rejection, or response selection; e.g., Hamblin-Frohman & Becker, 2021). Hence, if statistical learning and history effects can guide attention, we would expect learning and history effects to lead to a gradual increase in the proportion of first eye movements to the target in the probe trials. If the Eureka effect can affect early visual selection, it should produce a large, abrupt increase in first eye movements to the target immediately after the instruction that the probe target is always associated with a specific colour (see Figure 2 for a graphical representation). As it is possible that instructions have a slightly delayed effect on attention and may not affect the first eye movement in a trial (while still improving target selection), we will also examine the proportion of trials in which the target was fixated upon at any point in time during the probe trials. This measure was included to ensure that possible delayed effects on attention can still be detected in this experiment. If the Eureka effect can guide attention, we would expect similar results to the first eye movement measure, with a considerable spike after the instruction is given.

Figure 2.

Predicted Outcome Of The Relationship Between Accuracy And Time For Each Hypothetical Mediator Of Attention



Note. (Left) The relationship if history effects operated alone. (Middle) The relationship if the proposed 'Eureka' effect operated alone. (Right) An estimation of the combination of history effects and a sudden 'Eureka' effect. Also note that we predict a similar effect on the eye movement measures.

Methods

Participants

Twenty-six participants were recruited from the University of Queensland SONA system and compensated with credits towards their program requirement (Age *M* = 23.6, SD = 6.94, range = 18 – 54, 20 females, 6 males). One participant chose to discontinue the experiment and their data were removed. Upon providing consent (see Appendix A), participants were subjected to an Ishihara Test for Colour Blindness (Appendix B), to ensure normal colour vision. Plates 1, 3, 7, 18, and 22 were used as they allowed for a quick but effective colour deficiency test to ensure participants could engage with the tasks effectively. No participants were excluded on the basis of deficits in colour vision. Seven participants were excluded from the final analysis as they stated noticing the presence of critical information prior to being told. The final analysis contained 18 participants (Age $M = 24.1$, SD = 7.83, Range = 18 – 54, 14 Females, 4 Males). As this sample size yielded sufficient power (> 95% power required 15 participants), no additional participants were recruited. The experiment was approved by the University of Queensland Ethics Committee. All participants were briefed and debriefed regardless of their inclusion (see Appendices C and D).

Materials

The latest edition of Ishihara's Tests for Colour Deficiency was used to determine normal colour vision and responses to selected plates were recorded. Plates 1, 3, 7, 18, and 22 were used (see Appendix B).

Stimuli were provided to participants by the Presentation software (Neurobehavioral Systems) and presented on a 60Hz, 21.5 inch, 1920 x 1080 pixel computer screen (Dell Professional P2217H). The distance between the eye tracker and the computer monitor was kept constant at 600 mm.

Eye-tracking was performed by an Eyelink 1000 in a desktop configuration with a sampling rate of 500Hz. During the experiment, the participants' focus and eye movements were observed by the experimenters to ensure proper tracking and attention to the tasks. Participants responded to the stimuli via either a standard USB English labelled keyboard provided to them in the standard ANSI layout or a standard USB computer mouse.

Stimuli

Search Trials. The search trials contained an array of six shapes (diamond, L-shape, trapezoid, square, triangle, and circle, see Table 1 for sizes, Figure 3 for a visual representation, and Appendix F for stimuli used). The shapes all had identical colour (green) and contained greater-than (">") or less-than ("<") symbols, described as 'arrowheads pointing either left or right', as response-defining items. The symbols were printed in black using the typeface Arial Black at 18pt. The shapes were 7.16° of visual angle away from the central black fixation cross (0.47° x 0.47°) and arranged equidistantly in a diamond configuration (Figure 3). The target for the search trials was always the circle shape. The position of the target and distractors in the diamond configuration as well as the direction of the arrowheads were randomised across trials with the limitations that each display only contained a single shape of each kind, and that an equal number of left- and right-pointing arrowheads was presented inside the shapes.

Table 1.

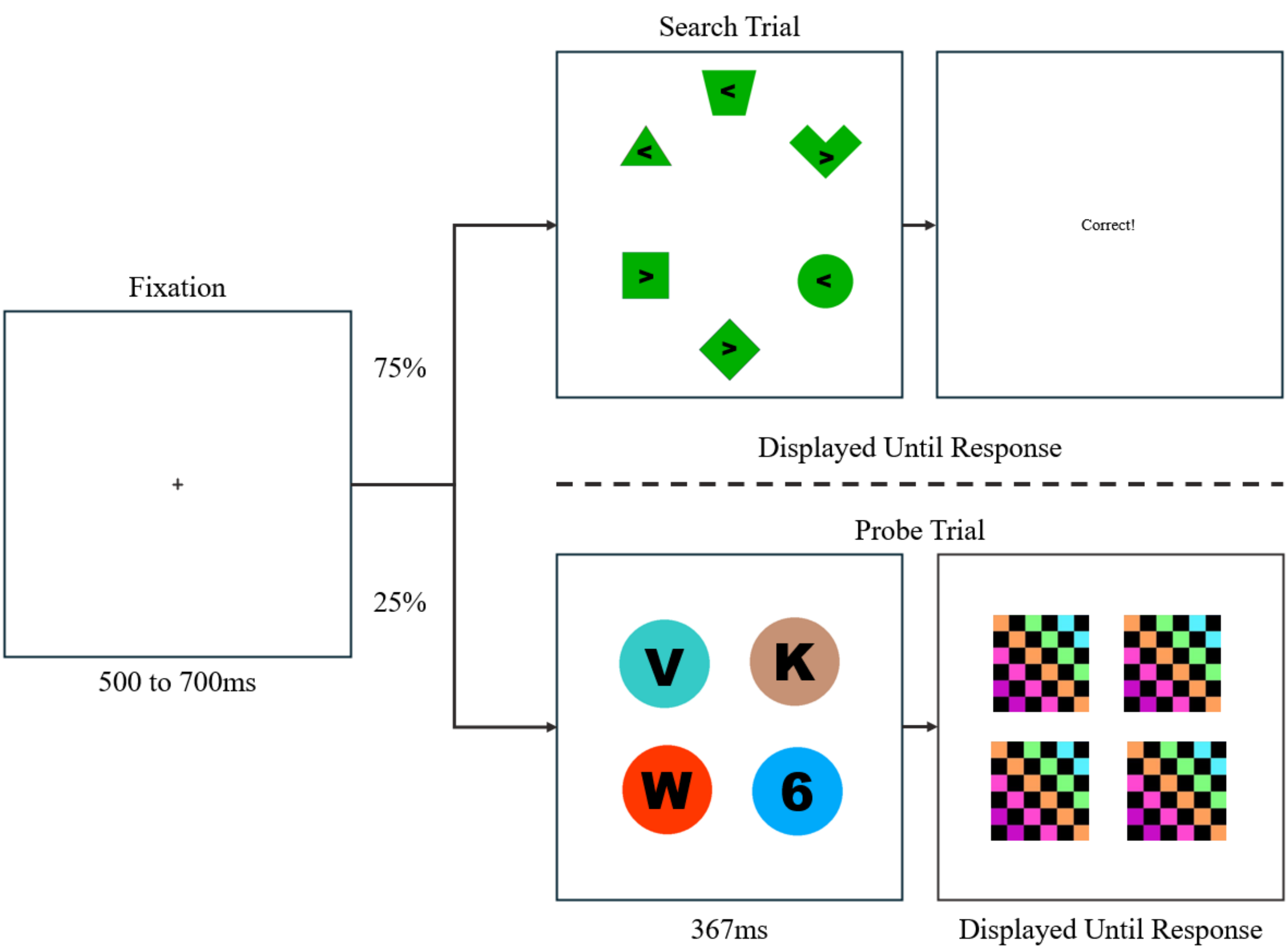
Seach Trial Stimuli With Measurements

Shape	Visual Angle (°)
Diamond	1.56 x 1.56
L-Shape	1.46 x 0.73
Isosceles Trapezoid	1.56 x 0.94
Square	1.13 x 1.13
Equilateral Triangle	1.65 (per side)
Circle	0.73 (Radius)

Probe Trials. The probe trials always contained the same four coloured circles: blue, turquoise, red, and brown (see Figure 3 for a visual representation and Appendix G the stimuli used), all 0.73° radius in size. The shapes were arranged in a diamond pattern array 7.16° visual angle away from the centre fixation cross (0.47° in height) equally to avoid colour after-effects from search trials. The target in the probe trials was a number between 2 and 9, while the distractor probes all contained letters (A, C, F, K, M, R, V, W, or Y; all printed in black in Arial 18pt). The number 1 and the other letters of the alphabet were not used as they might be confused with each other during the short presentation time. A backwards mask (2.36° x 2.36°) consisting of a colourful checkerboard pattern was displayed after the presentation time had elapsed.

Figure 3.

Flowchart Of Current Experiment



Note. An example of a trial after 16 practice trials and commencement of probe trials with weightings for each trial appearance and duration of trials. This is a diagrammatic representation; the stimuli are not to scale, see Appendices F and G for stimuli and Table 1 for sizes.

Design

The experiment consisted of 144 trials with a mixture of search trials (75%) and probe trials (25%; 36 trials). Probe trials were randomly interleaved into the sequence of search trials, with the limitation that the probe trials were separated from each other by ensuring that each probe trial was preceded by at least two search trials. The position of the target in search and probe trials were determined randomly on each trial. Similarly, the number constituting the target in probe trials was determined randomly on each trial. The probe target was always presented against the background of a blue circle to avoid possible skews in data towards more salient colours. The non-target letters in probe trials were drawn randomly (without replacement) and presented randomly on the three other, differently coloured circles.

The measures for the probe trials are accuracy of responses averaged by trial (accuracy), percentage of participants who saccade to the target stimuli for the duration of both the stimuli and the mask (target selected), and percentage of participants who saccade to the target stimuli first during both the stimuli and the mask (target selected first).

For a subset of analyses, the probe trials were segmented into pre (trials 1-20) and post (trials 21-36) trials, corresponding to the subset of trials before and after participants were asked whether they noticed anything unusual about the probe trials, and informed that the target number in probe trials was always presented on the blue disk. The experiment comprised 20 pre-trials completed without prior knowledge of the regularity and 15 post-trials, completed after the instruction to attend to the blue circle (as it always contained the target) was given. Trial 21 corresponded to the trial which we predict will show a large increase in accuracy if instructions can produce Eureka effects that in turn can guide visual attention.

Procedure

Participants were first provided with an information sheet (Appendix C) and asked to provide informed consent to participant in the experiment via a keyboard input (Appendix A). The Ishihara plates were then administered, and the results recorded (Appendix B). If no colour vision deficiencies were detected, participants were seated with their chin in a chin rest and their forehead resting against a forehead rest, while the eye tracker was calibrated with a 9-point calibration.

Prior to the start of the experiment, participants completed 16 practice trials in the visual search task only, which were not analysed. After the practice trials, a screen was displayed explaining the probe trials and how to complete them (Appendix E).

Prior to each trial, accuracy eye tracking was ensured with a fixation control: The search or probe display was only presented when participants maintained a fixation on the central fixation cross (< 1.18° from the centre), for a minimum duration of 500ms, plus a random time period of 0 – 200ms, within a time window of 2,000ms. Immediately after the fixation control, a search or probe display was presented.

In the search trials, the search stimuli were displayed until a response was recorded. Immediately after the response, trial feedback would be displayed consisting of the written words “Correct!”, for 500ms, or “Wrong!”, for 1000ms. The feedback display was followed by an intertrial interval of 250ms, during which a blank white screen was presented.

Probe displays containing the coloured disks, numbers, and letters were displayed for 367ms and immediately backwards masked with the coloured checkerboard masks. The mask display was presented until participants pressed one of the possible response keys (2 – 9).

Trial feedback was not provided for probe trials. The intertrial interval to the next trial was 1500ms. A diagrammatic view of this process can be seen in Figure 3.

Upon the completion of the 20th probe trial, participants were presented with a screen that encouraged them to take a break and talk with the experimenter. It was in this break that the experimenter would question the participant as to whether they had noticed any consistencies or (ir-)regularities with the probe trials. If participants answered that they had noticed that the target number in the probe trials always appeared in the blue circle, this would be confirmed, the experiment would continue, and their data removed afterwards. If participants indicated that they had not noticed anything or if they had noticed something innocuous or unrelated, it would be relayed to the participant that the target number always appeared in the blue circle. Participants would then be asked to use this information in further trials to improve their performance and the experiment continued. Upon completion of the 144th trial, the experiment would end, and participants were thanked and debriefed (see Appendix D).

Analysis

All statistical analyses were carried out in the Jamovi software (The jamovi project 2022) and utilising the 'jsq' package (Clyde et al., 2011; Clyde, 2011; JASP Team 2018; Ly et al., 2018; Ly et al., 2016; Morey, 2018; Rouder et al., 2009), the 'moretests' package (Fox, 2020), and the 'rj' package (R Core Team 2021).

Before conducting any statistical analyses to evaluate the hypotheses, assumption checks were conducted on our data, including skewness and kurtosis analysis to determine distribution characteristics, univariate outlier checks to investigate extreme values, normality through a Shapiro-Wilk's test, independence of errors through a Durbin-Watson test, and a heteroscedasticity check through a Breusch-Pagan test. An autocorrelation test was not conducted as autocorrelation of trials would be present due to predicted learning effects and the time component.

Where appropriate, the Bayesian approach was used throughout the analysis in addition to conventional statistics, including effect size measurements (Cohen's d). Table 2 contains the generally accepted interpretation of Bayes Factors as described by Lee & Wagenmakers (2013).

Table 2.

Interpretation of Bayes Factors (Lee & Wagenmakers, 2013).

Bayes Factor	Interpretation
>100	Extreme Evidence for H_1 as compared to H_0
30 - 100	Very Strong Evidence for H_1 as compared to H_0
10 – 30	Strong Evidence for H_1 as compared to H_0
3 – 10	Substantial Evidence for H_1 as compared to H_0
1 – 3	Anecdotal Evidence for H_1 as compared to H_0
1	No Evidence
1/3 – 1	Anecdotal Evidence for H_0 as compared to H_1
1/10 – 1/3	Substantial Evidence for H_0 as compared to H_1
1/30 – 1/10	Strong Evidence for H_0 as compared to H_1
1/100 – 1/30	Very Strong Evidence for H_0 as compared to H_1
< 1/100	Extreme Evidence for H_0 as compared to H_1

Data

Data from the Eyelink parsed into saccades, fixations, and blinks. An eye movement was classified as a saccade if it had a velocity over 30°/s. A fixation was classified as such if the participants' gaze was within 1° of a stimulus and no saccade was occurring (velocity < 30°/s) and there were no blinks. Blinks were detected by a complete loss of tracking.

As the stated purpose of search trials was to reduce participant likelihood of noticing similarities between probe trials, the accuracy and eye tracking data of the search trials was not analysed.

Any participant who reported that the target number was in the blue circle in the probe trials during the break was excluded (24%). As participants were allowed as much time as needed to respond to probe trials, no trials were excluded because of long RT, leading to a high average response time (M = 1,511 ms).

Accuracy, response time, target selected, and target selected first were all normally distributed with skewness and kurtosis values below conventional significance thresholds ($\alpha < .05$). The percentage of first saccades to target had a peak in the distribution around the value 22.2% (K = 2.81) (Hair, 2014). Univariate outlier checks found that trial 19 was an outlier with regard to target selected and target selected first measure. This outlier is visible in Figure 6 and 7. Checking the assumption of normality for the residual scores showed that most residuals were normally distributed, however, the target selected first measure significantly deviated from a normal distribution. This makes sense as we would not expect these measures to be particularly normally distributed, as target selected first has the previously identified outlying residual. Independence of errors was assessed and found to be within acceptable limits for all variables. Heteroskedasticity was also found to be within acceptable parameters (Breusch & Pagan, 1979) (See Appendix H for full results).

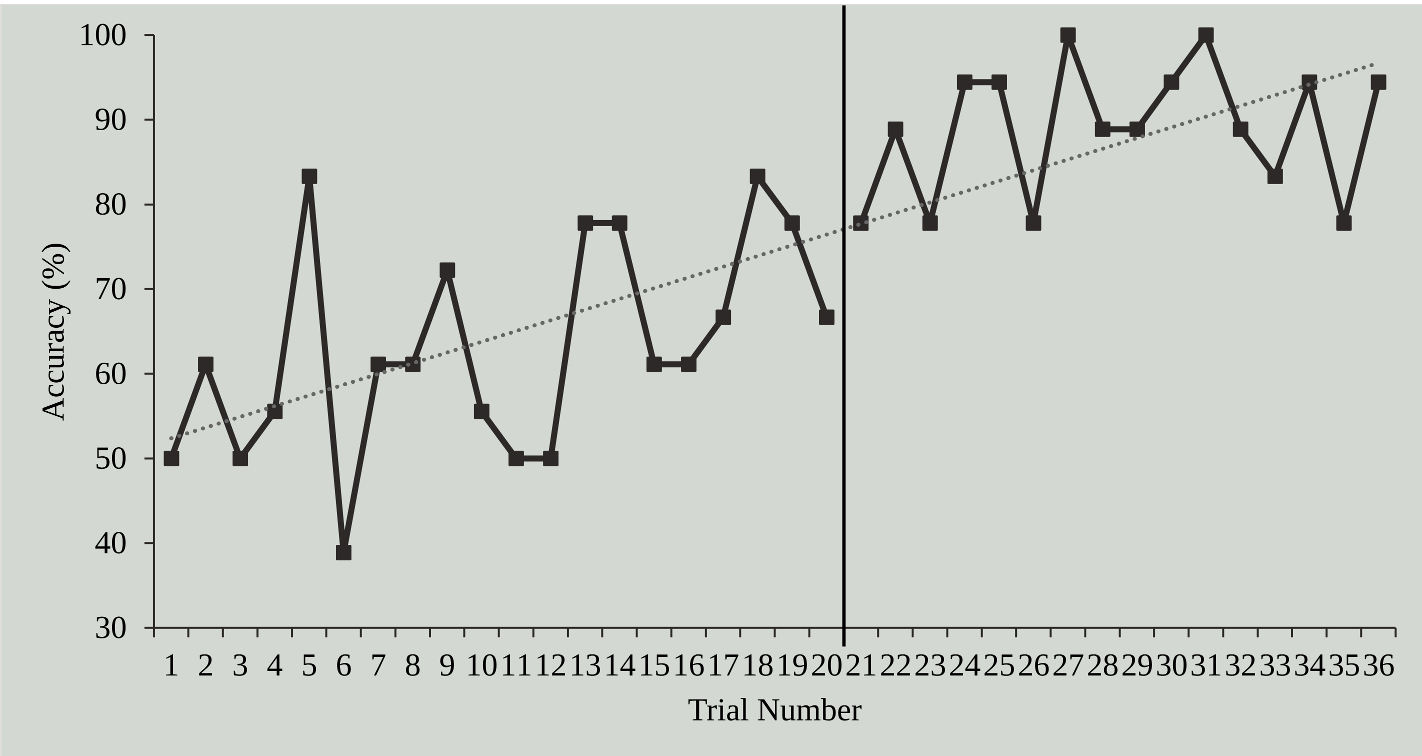
Results

Mean accuracy. To assess whether performance on the probe task improves with learning or due to a Eureka effect, we used a paired samples *t*-test to compare pre- to post-instruction trials. In addition, linear regressions were be conducted on per-trial accuracy to assess how much variance in the data could be explained by gradual learning and history effects alone. As predicted, the results of the *t*-test revealed that there was very strong evidence that response accuracy was higher in post-instruction trials (M = 84.6, SD = 19.1) as compared to pre-instruction trials (M = 60.8, SD = 11.9) ($t(16) = 4.37$, d = 1.06, $p < .001$,

BF_{10} = 72.3). Moreover, the results of the regression analysis showed that accuracy increased extremely linearly with trial number ($F(34) = 58.7$, $R^2 = .633$, $p < .001$, $BF_{10} > 100$), with 63% of the variance in the data explained by gradual learning and trial history effects (See Appendix I for the full statistics table). Figures 4 describe this linear relationship. This result is interesting, as strong history / learning effects have yet to been shown in trials with interleaved irrelevant trials, only directly repeating trials (Maljkovic & Nakayama, 1994).

Figure 4.

Percentage Of Correct Target Identification Responses Depicted Seperately For Each Trial, With A Linear Regression Trend Line.

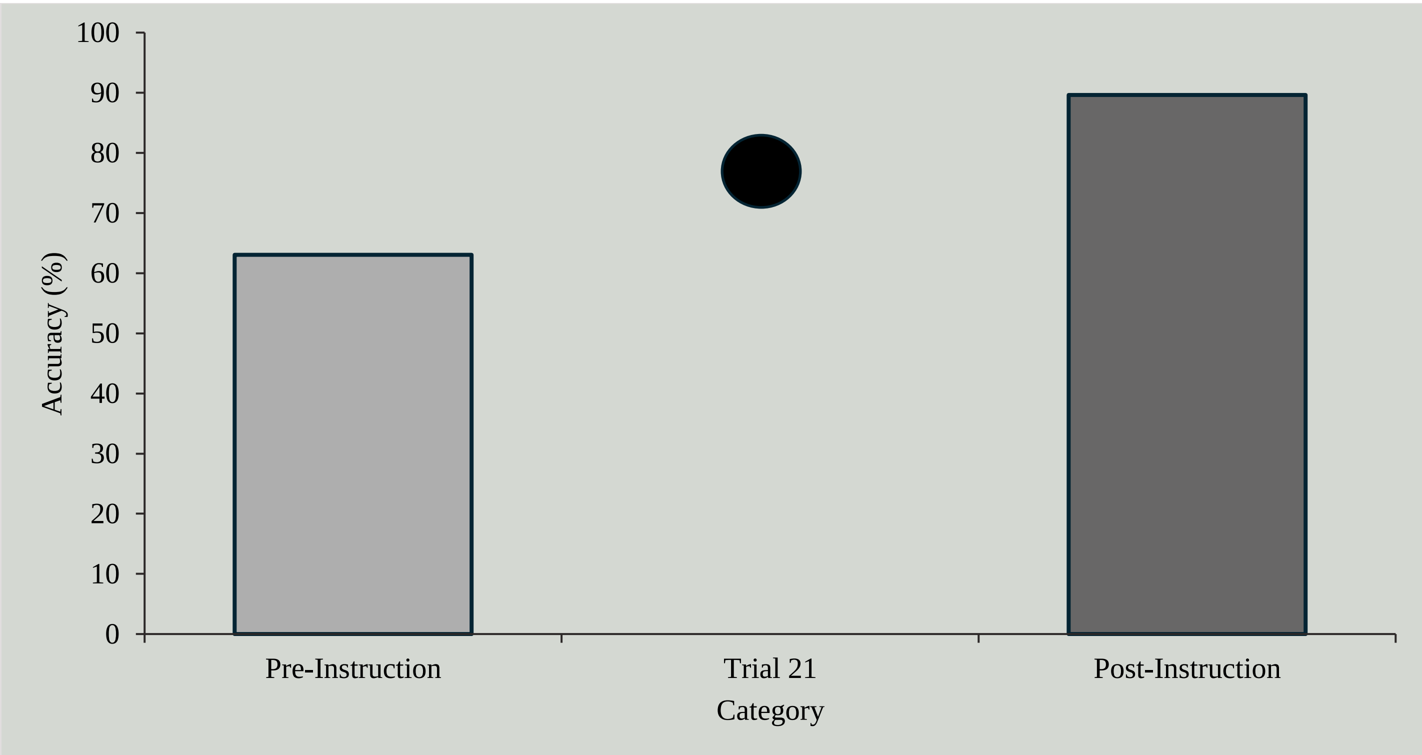


Note. The solid black line delineates pre- and post-instruction trials, with the instruction occuring between trials 20 and 21.

In order to assess whether the instruction to attend to the blue disk allows participants to efficiently select the target in a similar fashion to a Eureka effect, the accuracy on trial 21 (which immediately followed the instruction) was compared to the mean accuracy of pre-instruction trials and the remaining post-instruction trials (excluding trial 21). Paired, two-tailed one-sample *t*-tests revealed that mean accuracy on trial 21 ($M = 77.8$) was extremely different from pre-instruction ($t(19) = 5.27$, d = 1.18, $p < .001$, $BF_{10} > 100$) and not different in post-instruction ($t(16) = 1.47$, d = 0.38, $p = .160$, $BF_{10} = 0.62$) trials (see Figure 5). To ensure that comparisons involved trials with similar amounts of trial history effects, the accuracy of trial 21 was compared with the eight trials surrounding trial 21. Paired, two-tailed one-sample *t*-tests showed that there was no evidence that trial 21 differed from either the four preceding trials (Trials 16 - 20: $M = 73.6$, SD = 8.33, $t(3) = -1.01$, d = -0.50, $p = .389$, $BF_{10} = 0.265$), or the four following trials (Trials 22 - 25: $M = 88.9$, SD = 78.6, $t(3) = 2.82$, d = 1.41, $p = .067$, $BF_{10} = 1.97$) (Appendix J for the full statistics table).

Figure 5.

Percentage Of Correct Target Identification Responses Depicted Separately For Pre-Instruction, Post-Instruction, and Trial 21.



Note. Pre-instruction trial constituted trials 1 – 20. Post-instruction trials constituted trials 22 – 36.

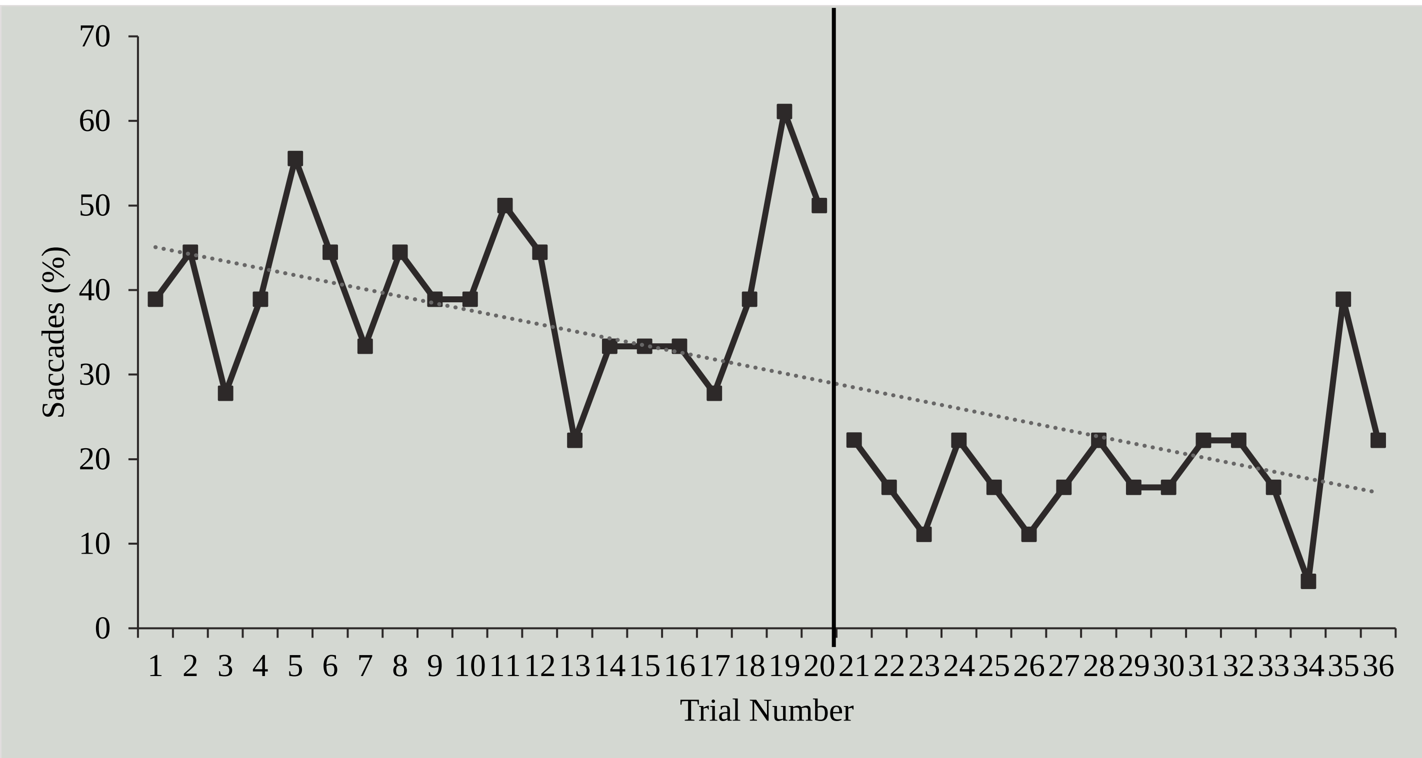
Next, to examine whether learning and trial history effects could fully account for performance on trial 21, the previous regression was used to test whether performance on trial 21 was within the performance predicted by gradual learning and trial history effects (see Gibson & Jiang, 1998 for a similar procedure). The results showed that target identification accuracy of trial 21 was only 0.007 standard deviations away from the value predicted by the linear regression (see Figure 4). This lack of a spike in performance may imply an absence of a Eureka effect, or an inability to use the Eureka effect to guide attention.

Target Fixations. As manual responses can be contaminated by later, post-selection processes that commence after target selection, the percentage of trials in which the first eye movements were to the probe target was analysed. The results of a paired samples *t*-test revealed that target selection was extremely different in pre-instruction trials (*M* = 40, SD = 9.40) and post-instruction trials (*M* = 18.75, SD = 7.05) ($t(14) = 6.61$, d = 1.71, $p < .001$, $BF_{10} > 100$). The proportion of trials selected first was similar, with pre-instruction trials (*M* = 23.06, SD = 7.91) and post-instruction trials (*M* = 13.89, SD = 7.60) ($t(14) = 3.37$, d = 0.87, $p = .005$ $BF_{10} = 7.88$) being substantially different (see Figures 5 and 6). However, this relationship is negative, as there was an extreme linear decrease both in the percentage of trials in which the target was selected, ($F(34) = 23.3$, $R^2 = .407$, $p < .001$ $BF_{10} > 100$) and an anecdotal but marginally significant linear decrease in the proportion of first eye movements to the target, ($F(34) = 4.17$, $R^2 = .109$, $p = .049$, $BF_{10} = 1.56$) (see Appendix K for the full statistics table). This may indicate that a floor effect is occurring as eye movements to any stimuli in general is decreasing.

As with accuracy, the relationship between the pre and post trials eye movements to trial 21 eye movements was analysed. The results of the paired, two-tailed one-sample *t*-tests revealed that mean target selection on trial 21 (*M* = 22.2) was extremely different from pre-instruction trials (*M* = 39.2, SD = 10.2, $t(20) = 7.64$, d = 1.67, $p < .001$, $BF_{10} > 100$) and anecdotally different from post-instruction trials (*M* = 18.5, SD = 7.22, $t(14) = -1.91$, d = -0.49, $p = .076$, $BF_{10} = 1.12$). Additionally, two-tailed one-sample *t*-tests revealed that mean target selected first on trial 21 (*M* = 11.1) was extremely different from pre-instruction trials (*M* = 22.5, SD = 8.3, $t(20) = 6.26$, d = 1.37, $p < .001$, $BF_{10} > 100$) and not different from post-instruction trials (*M* = 14.1, SD = 8.1, $t(14) = 1.42$, d = 0.37, $p = .178$, $BF_{10} = 0.590$).

Figure 6.

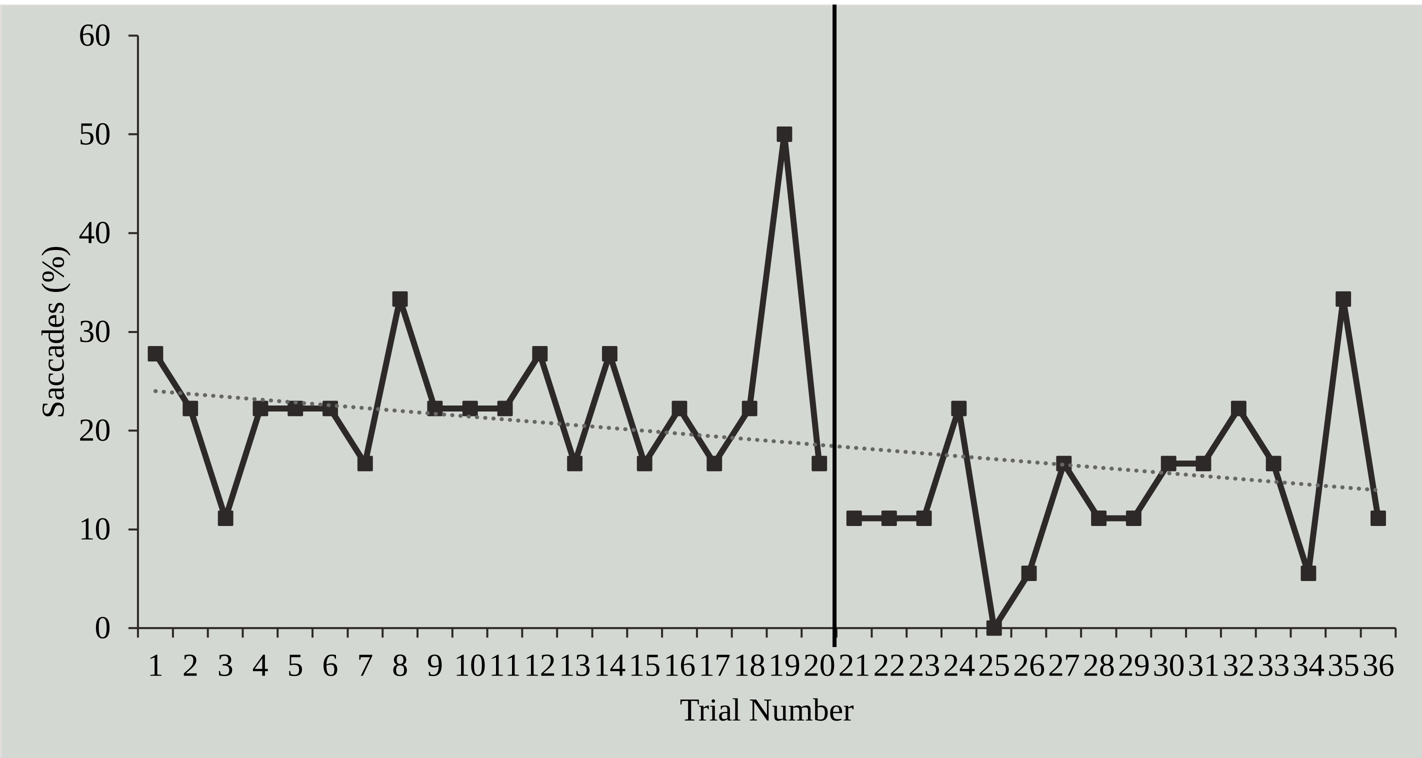
Percentage Of Eye Movements To The Target In Probe Trials, With A Linear Regression Trend Line.



Note. The solid black line delineates pre- and post-instruction trials, with the instruction occuring between trials 20 and 21.

Figure 7.

Percentage Of First Eye Movements To Target In Probe Trials, With A Linear Regression Trend Line.



Note. The solid black line delineates pre- and post-instruction trials, with the instruction occuring between trials 20 and 21.

Again, to examine whether learning and trial history effects could fully account for eye movements on trial 21 the previous regression was used to test whether performance on trial 21 was within the performance predicted by gradual learning and trial history effects. Doing the same analysis as accuracy, we took the four surrounding data points each side of trial 21 and compared them to the value of trial 21. For target selection, there was no evidence to suggest that trial 21 differed from either the four preceding (Trials 16 - 20: *M* =

44.44, SD = 12.42, $t(3) = 3.10$, d = 1.55, $p = .053$, $BF_{10} = 0.145$) or proceeding trials (Trials 22 - 25: $M = 16.67$, SD = 3.93, $t(3) = -2.45$, d = -1.22, $p = .092$, $BF_{10} = 0.473$). The same is true for target selection first (Trials 16 - 20: $M = 26.39$, SD = 13.86, $t(3) = 1.91$, d = 0.96, $p = .151$, $BF_{10} = 0.823$, Trials 22 - 25: $M = 11.11$, SD = 7.86, $t(3) = 0$, d = 0, $p = 1$, $BF_{10} = 1.12$) (see Appendix K for the full statistics table). The results also showed that the target selection of trial 21 was -0.60 standard deviations away from the value predicted by the linear regression (see Figure 6). Target selected first was -0.84 standard deviations away (see Figure 7).

This discrepancy between accuracy and eye movements may indicate that participants learnt to suppress their eye movements in the probe trials and relied mostly on covert attention on probe trials. Covert attention is the ability to voluntarily or involuntarily attend to a part of vision not within the fovea (Carrasco & McElree, 2001). It has been found that the ability to deploy and the effectiveness of covert attention increases with task familiarity (Zhang et al., 2022). If this is true for this investigation, trial accuracy should correlate with the decrease in both target selection and target selected first. A Pearson's analysis found an extreme correlation between trial accuracy and target selection ($r(34) = -0.60$, $p < .001$ $BF_{10} > 100$) and a substantial correlation between trial accuracy and target selected first ($r(34) = -0.34$, $p = .042$ $BF_{10} = 4.97$) (see Appendix K for the full statistics table).

Discussion

Summary of Results

In the current study, a novel paradigm was utilised using unique methods of visual information obfuscation to investigate how and to what extent verbal instruction alone could motivate top-down tuning to guide attention. This builds on current knowledge by identifying gaps and short falls in previous methodologies (Bacon & Egeth, 1994; Duncan &

Humphreys, 1989; Folk & Remington, 1998). Mainly, the understanding that history effects may contaminate our understanding of pure top-down tuning. It was expected that a 'Eureka'-type effect could be present in the early stages of visual processing and could give participants the tools to improve their search strategies. If this were the case, we would expect to see a jump in measures associated with task performance in the first trial after instructions are given as participants use this pure top-down tuning to attend to targets. These measures were trial accuracy, proportion of trials in which there were eye movements to the target, and proportion of trials in which the first eye movement was to the target. These measures were interpreted namely through the use of Bayesian factor analysis and traditional t-tests, linear regressions, and a Pearson's correlation.

Accuracy Decidedly, we did not see the jump we had predicted. Accuracy was extremely correlated with trial number and increased extremely linearly throughout the duration of the experiment. This was in line with what we expected from trial history effects. We expected there to be a clear and significant jump in accuracy in the first post-instruction trial, and while it was significantly different from pre-instruction trials, there was no evidence to suggest it was different from post-instruction trials. This is easily explained through intertrial learning effects increasing trial 21 above pre-trial accuracy average (Maljkovic & Nakayama, 1994) and simultaneously creating a ceiling effect in the post-instruction trials. We saw no evidence of a significant jump in the first post-instruction trial compared to trials close to it temporally. While the results from the mean accuracy measures did not support our hypotheses, there is new information here. Strong learning effects have yet to be shown in trials that contain interleaved irrelevant trials, only serial, repeated trials or an interleave of related but distinct trials. Regardless, our results show clear learning and intertrial effects with the linear increase in accuracy and with no sudden transient post-instruction as seen in previous research (Duncan & Humphreys, 1992; Duncan & Humphreys, 1989); it is clear that the new information given was ineffective. Why is this? To answer, we can look to the eye movement data.

Eye Movements It was expected that both target selection and target selected first would increase linearly with trial number. We observed target selection decreasing extremely linearly and observed target selected first decreasing anecdotally but significantly with trial number. We also see extreme and substantial differences between pre- and post-instruction trials in target selection and target selected first respectively. If eye movements to the target are decreasing while accuracy is increasing, immediately this points us in the direction of the deployment of covert attention (Carrasco & McElree, 2001). This disconnect between target selection and target selected first's trends may imply that over the duration of the task, even after receiving the critical information, the target stimulus doesn't become salient enough to draw attention. So covert attention is being deployed, but in a target-agnostic way. We know that covert attention increases with task familiarity (Zhang et al., 2022), so, we would also expect to see a decrease in eye movements as participants become more familiar with the task, which we do. However, we don't see a sharp spike post-instruction around surrounding trials as participants become even more familiar with the task. This is perplexing, as it has been shown that implicit learning can increase eye movements (Yuan-Chi & Chiang-Shan Ray, 2004). This indicates to us two potential explanations: participants are not utilising the new information to better their search strategy or, the duration of the stimuli is too short to allow eye movements to the target.

Results from trial 21 don't better support our hypotheses. Trial 21 in target selection was extremely different from pre-instruction and only anecdotally different in post-instruction trials. Target selected first was similar, experiencing a floor effect in post-instruction trials. This may be the same ceiling (in this case floor) effect we see with the accuracy results. As participants become more performant on the task, they may require less investigatory fixations (Greene & Rayner, 2001). This finding is compounded by the analysis of trials close to trial 21, which show no evidence for a difference between them. The case for intertrial / history effects working alone to create the results we see here grows with the correlation between accuracy and lower eye movement measures, which we found to be extreme in the case of target selection and substantial in the case of target selected first.

Looking at the data further, we see a very clear spike in both eye movement measures in trial 19. This result is very unusual, as there was no change or indication of any upcoming change in the experiment's routine, nor any change prior. One explanation might be that it is at this point participants are familiar enough with the task and begin to be able to fixate on the target (Becker et al., 2009; Duncan & Humphreys, 1989; Zhang et al., 2022). This is not to say that participants knew of the critical information, they were simply getting better through trial history effects. We might not see a continuation of these effects past trial 21 due to the interruption. This may affect their search strategies by overloading participants with new information (Cambronero-Delgadillo et al., 2024).

To answer the question of why we don't see the jumps and relationships we predicted based on previous research, we only have to look so far as our methodology. It was originally decided trial feedback was not to be provided to participants at the end of any single probe trial to avoid tipping-off participants to the critical information any more than was necessary. If we told them they were correct in picking a coloured disk, they might catch on quicker, leading to high(er) participant attrition. This, we believe, is the reason why we don't see what we hypothesised. Participants were not motived to change their search strategies to better complete the task as they had no idea how well they were performing (Leber & Egeth, 2006). To them, they had a sufficient search strategy. We know that in visual search tasks, the already implemented strategy often supersedes new strategies in terms of participant choice, even if the new strategy is more effective (Irons & Leber, 2018). The balancing act of revealing enough information to make the task performant whilst hiding enough to see a theoretical increase has fallen to one side. As it stands, it is difficult to fully reject or accept the hypotheses we set out. The methodological shortcomings identified with our current experiment have caused this. We believe that with changes, such as task feedback, and tweaking of stimuli presentation time, this paradigm can adequately investigate the true effect of top-down tuning moderated through verbal instruction alone.

Implications

Implications for top-down tuning in the current study are difficult to make due to these above-mentioned issues with the paradigm. What we can take away from the investigation is that history effects are available and strong in guiding attention in the current task. We can also imply that the accuracy of responses to a task such as this are not able to be completely predicted by the current eye movement measures, as we start to see floor effects in target selected first before we see a ceiling effect in accuracy. Therefore, the full gamut of performance is not able to be represented in this particular measure. This may be due, as mentioned, to an apparent increase in the deployment of covert attentional resources, something that we cannot inherently measure with our current tools.

Despite not finding results in support of our hypotheses, there are still some worthwhile theoretical implications here. History / learning effects of this strength have not been shown in interleaved trials that contain irrelevant tasks as they have been shown here. The implication here is that history effects might be able to survive a certain number of irrelevant trials and still guide attention. This obviously requires further and more focused research to understand the nature and strength of the survivability, however this initial finding points to the resilience of history effects.

Limitations

Participant attrition was noticeably high in our investigation. However, participants were excluded through criteria decided before data collection began. They were only excluded due to noticing of the critical information. Moreover, the number of participants recruited satisfied our power analysis and our results are in-line with previous research when we consider the other shortcomings of our methodology (insofar as we see clear history effects) (Duncan & Humphreys, 1992; Duncan & Humphreys, 1989). However, while we had sufficient power, these data are clearly quite noisy, as is evident from the (relatively unexplainable) spikes at trial 19 in target selection and target selected first.

The most obvious and glaring limitation with the current study, as mentioned, was the lack of task feedback during the probe trials. We suggest that if participants were given task feedback, it would better address the aim of this investigation. We know that attentional capture can be reward driven, as outlined by Anderson (2011). It is this lack of reward in the current paradigm, we believe, fails to push participants to adapt their search strategies to incorporate the critical information. Thus they rely solely on "non-'Eureka'" top-down tuning and unavoidable history effects for the duration of the tasks. Additionally, the split of 75% search trial to 25% probe trials may have motivated participants to invest more cognitive resources into search trials than probe trials. This is compounded by the fact that search trials gave feedback, further incentivising cognitive resource allocation.

It is also possible that the short presentation time of the stimuli in probe trials didn't allow for participants to incorporate the relatively slow process of top-down tuning (Hamblin-Frohman et al., 2022). The presentation time of probe trials in the current study was determined through pilot testing with the goal of observing neither floor nor ceiling effects in accuracy of response. We did not incorporate the critical trial in this phase of piloting, as this could have impacted our *a priori* interpretation of the current study. It is possible that this tuning of presentation time biased the paradigm towards history effects dominating attention, leaving little room for top-down tuning to be investigated.

The stimuli set used in our investigation was static. The choice of the stimuli was based on the understanding that colours themselves are highly salient (Itti et al., 1998). Having one disk be more salient than another posed an issue. We therefore aimed to have four colours (somewhat) equally salient to one another while also allowing for the critical information to guide attention to a feature that is salient enough. It is not clear from the results if one disk was more salient than another on the pre-instruction trials, but without controlling for this, it is impossible to say either way.

Future Research

Future research is needed to investigate factors such as time between trials, interruptions, and switch costs, on history effects and intertrial learning to better understand their role in complex tasks. A hypothetical investigation could look at the relationship between intertrial learning and the duration or count of irrelevant tasks in-between critical tasks. The same pitfall of cognitive resource allocation that has been identified in the current study should be avoided if possible.

Future research into top-down tuning's effect alone should incorporate the shortcomings in the paradigm highlighted above. Namely providing participants with task feedback, incorporating appropriate rewards for correct responses (this could be simply the feedback provided), higher statistical power through increased participant count, and tuning of presentation time and stimuli set. Research further focusing on top-down tuning's role in attentional guidance is important to better our understanding not only of its role in visual search, but the role of bottom-up feature contrast and history effects as well.

Contributions and Artificial Intelligence disclosure

The design of the current experiment was inspired partly by the paradigm present in Hamblin-Frohman et al. (2022). However, through the many iterations it has undergone, the current design is much divorced from its original birthplace. The current experiment was designed in consultation with my supervisor who also programmed the experiment. The data was collected by myself and others under my supervisor. Data processing, analysis, interpretation, and figure creation was conducted by myself with assistance from my supervisor.

A Large Language Model or any other 'AI' was not utilised in any capacity in this thesis. Save the built-in spellchecking capabilities of Word, no other checking or reviewing software was utilised.

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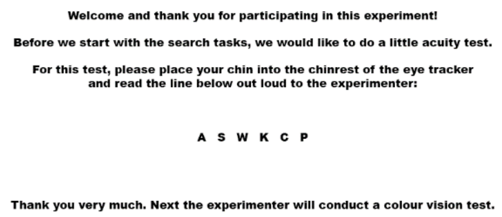
Appendix A: Consent Screen

Press the Y key on the keyboard to express your consent ot participate in this study, and for the experimenter to undertake all procedures as outlined in the information sheet that was provided to you.

Note. Transcript: Press the Y key on the keyboard to express your consent to participate in this study, and for the experimenter to undertake all procedures as outlined in the information sheet that was provided to you.



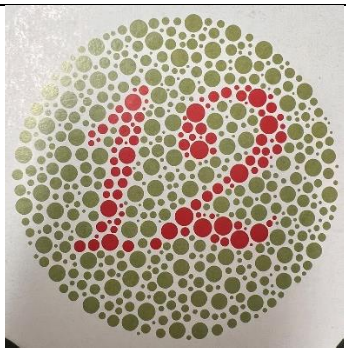
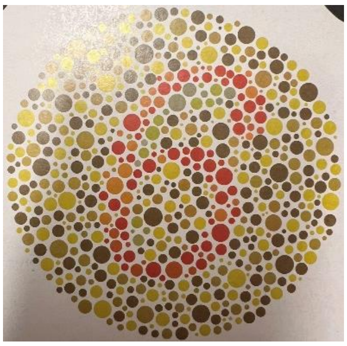
Note. Transcript: Welcome and thank you for participating in this experiment. Before we start with the search tasks, we would like to do a little acuity test. For this test, please place your chin into the chinrest of the eye tracker and read the line below out loud to the experimenter. A S W K C P. Thank you very much. Next the experimenter will conduct a colour vision test.

Appendix B: Ishihara

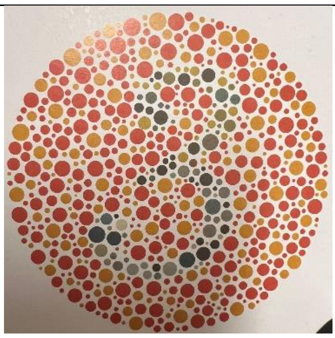
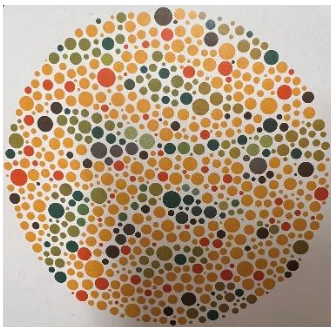
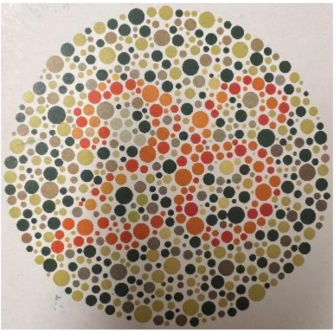
A blank example of a single participants results from the Ishihara test.

Participant Initial	Plate Number	Normal	Red/Green Deficiency				Total Colour Blindness/Weakness	Participant Score
	1	12	12				12	
	3	6	5				Nothing	
	7	3	5				Nothing	
	18	Nothing	5				Nothing	
			Protan		Deutan			
			Strong	Mild	Strong	Mild		
	22	26	6	(2)6	2	2(6)	Nothing	

The Ishihara plates used and their corresponding number

Plate	Number in catalogue	Number perceived by normal colour vision
	1	12
	3	6

Note. Table continues on next page.

Plate	Number in catalogue	Number perceived by normal colour vision
	7	3
	18	None
	22	26

Appendix C: Brief

Participant Information Sheet

For the study: Visual Search

The purpose of the study
The purpose of this study is to examine how visual attention is allocated to stimuli in a visual scene. In particular, the study examines whether and to what extent contextual factors can guide visual attention and determine eye movements in visual search. This study is being conducted by Dr. Stefanie Becker's Honours students from the School of Psychology, The University of Queensland, as part of their research project.

Participation and withdrawal
Participation in this study is completely voluntary and you are free to withdraw from this study at any time without prejudice or penalty. If you wish to withdraw, simply stop completing the exercises. If you do withdraw from the study, the materials that you have completed to that point will be deleted and will not be included in the study.

What is involved
Participants in this study are asked to respond to specific, pre-defined stimuli in computer-based experiments. During the experiment, the eye movement behaviour will be examined with a video-based eye tracker. Participation in this study will take one hour or less.

Risks
Participation in this study should involve no physical or mental discomfort, and no risks beyond those of everyday living. If, however, you should find any part of the procedure to be invasive or offensive, you are free to omit your responses, or to stop participating in the study.

Confidentiality and security of data
All data collected in this study will be confidential. Specifically, participants' will not be asked to provide their name or any other data that could identify them for the study. Identifying information such as on the receipts for payments will not be linked in any way to the experimental data. People participating in this study will be numbered and these numbers will not be able to be linked to any individual. The data will be seen only by the chief investigator and the research team. The data from this study will only be used for research purposes.

Ethics Clearance and Contacts
This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council's guidelines. You are of course, free to discuss your participation in this study with project staff (s.becker@psy.uq.edu.au). If you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 3365 3924.

If you would like to learn the outcome of the study in which you are participating, you can contact me at the email address given above, and I will send you an abstract of the study and findings as soon as these are available.

Thank you for your participation in this study.

(Stefanie Becker)

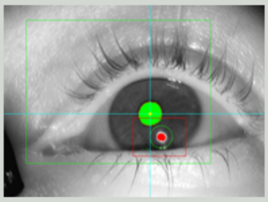
Appendix D: Debrief.

Participant Debriefing Sheet

Purpose and Background:
We cannot process all information present in a visual scene. *Selective Attention* refers to the mechanisms used to select visual information for further in-depth processing. The present study examines how attention is allocated to stimuli in a visual scene, and to determine the factors that drive visual attention.

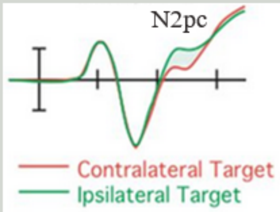
Measuring Attention:
Manual Response Time and Accuracy. Selected or attended stimuli are processed with high priority. This thus will usually result in shorter response times (RTs) and higher accuracy to attended than non-attended stimuli (e.g., Posner, 1980). Hence, measuring the behavioural responses already allows us to draw conclusions about which stimuli were attended first.

Eye Movements. More fine-grained information about the time-course of visual selection can be gained by measuring an observer's eye movements. Previous studies have shown that an eye movement to a location is usually preceded by a covert attention shift to that location (e.g., Deubel & Schneider, 1996), so that we can use eye movements to index which stimuli were attended. In advance to manual RTs and errors, eye movements provide fine-grained spatial and temporal information about which stimuli were selected when.



Most eye trackers measure the pupil and the so-called *corneal reflex* (CR), which is a reflection caused by the Purkinje cells in the retina. During eye movements, the CR's position relative to the pupil changes in a systematic fashion, which allows the eye tracker to determine the current gaze direction.

Electroencephalogram (EEG). In EEG experiments, participants wear a cap with electrodes that measure the neural activity of the brain by computing the relative differences in electrical activity between different electrode locations. When we attend to a stimulus in a particular location, this will result in characteristic changes of the waveforms recorded in visual and parietal cortices. Specifically, we will observe a higher negativity contra-lateral to the side that was attended. The corresponding component in the EEG is called the *N2pc* and can be used to infer whether attention was allocated to a particular stimulus (e.g., Eimer, 1996).



Experimenting:
Previous research has shown that how we allocate attention can be influenced by a variety of factors. For instance, emotional stimuli, stimuli with a contrast, or stimuli that are relevant to the task can all influence how we allocate attention. To learn more about the mechanisms driving attention, we typically systemtically *vary the stimuli* across different conditions – for instance, contrasting attention to an emotional face to a non-emotional face (or high vs. low contrast stimuli, etc.). If a stimulus indeed attracts attention, it should produce visible effects in the underlying measures (see above), allowing us to extend our understanding of the factors that determine attention and further refine corresponding theories.

If you have any questions about the present experiment, please feel free to contact the project leader (Stefanie Becker, s.becker@psy.uq.edu.au).

References:
Posner (1980). Orienting of Attention. *Quarterly Journal of Experimental Psychology*, 32, 3-25.
Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, 99, 225-234.
Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, *36*, 1827-1837.

Appendix E: Probe Trial Explanation.

Thank you for completing the first part of this task.
From here on, you will continue to do the same task. However, on some trials, you will have a different task:
On some trials, you will see a different set of displays, containing four differently coloured circles (e.g. blue, brown, red, cyan). One of the circles will have a number (2-9), while the others will have letters.
The display will be presented only briefly and then masked with checkerboards. Please try to remember the number you saw and press one of the numbers 2-9 on the keyboard to indicate which one you saw. If you did not see the number, please guess.

Please try to respond as accurately as possible in reporting the number.

Transcription: Thank you for completing the first part of this task. From here on, you will continue to do the same task. However, on some trials, you will have a different task: On some trials, you will see a different set of displays, containing four differently coloured circles (e.g. blue, brown, red, cyan). One of the circles will have a number (2-9), while the others will have letters. The display will be presented only briefly and then masked with checkerboards. Please try to remember the number you saw and press one of the numbers 2-9 on the keyboard to indicate which one you saw. If you did not see the number, please guess. Please try to respond as accurately as possible in reporting the number.

Appendix F: Search Trial Stimuli.

Stimuli	Name	Size (Visual Angle °)
	Green Diamond	1.56 x 1.56
	Green L-Shape	(0.73 x 0.73)[3]
	Green Isosceles Trapezoid	1.56 x 0.94
	Green Square	1.13 x 1.13
	Green Equilateral Triangle	1.65
	**Green Circle (Target)**	0.73 (Radius)
<	Left Arrow	0.28 x 0.28
>	Right Arrow	0.28 x 0.28

Appendix G: Probe Trial Stimuli

Stimuli	Name	Size (Visual Angle °)
	**Blue Circle (Target)**	0.73 (Radius)
	Brown Circle	0.73 (Radius)
	Red Circle	0.73 (Radius)
	Turquoise Circle	0.73 (Radius)
	Mask	2.36° x 2.36°
2,3,4,5,6,7,8,9	Numbers	~ 0.28° x 0.28°

Appendix H: Assumption Checks

	Accuracy	Response Time	Target Selected	Target Selected First	Pre	Post
Skewness	-0.286	-0.048	0.226	0.91	0.096	-0.309
Kurtosis	-0.996	-0.651	-0.718	2.81	-0.749	0.111
Shapiro-Wilk W	0.943	0.980	0.960	0.918	0.968	0.962
Shapiro-Wilk p	.065	.730	.215	.011	.751	.677
Breusch-Pagan BP	0.172	2.53	2.33	2.45	0.953	0.0005
Breusch-Pagan p	.461	.112	.127	.117	.329	.981
Durbin-Watson DW	1.38	1.79	0.564	0.233	0.547	0.154
Durbin-Watson p	.054	.392	<.001	<.001	<.001	<.001
Cook's Distance	0.0242	0.0277	0.0321	0.0426	0.0577	0.363

Appendix I: Mean Accuracy Statistical Analyses

Descriptive Statistics of Pre- and Post-Instruction trials across participants.

Measure	Pre	Post
N	20	17
Missing	0	0
Mean	63.1	84.6
Median	61.1	88.9
Standard deviation	12.5	19.1
Minimum	38.9	16.5
Maximum	83.3	100

Bayesian + Classical Pair Samples T-Test

	Student's t	df	p-statistic	Cohen's d	BF_{10}	Error %
Pre – Post	4.37	16	< .001	1.06	72.3	2.52e-9

Note. $H_a\ \mu_{Pre\ -\ Post} < 0$

Bayesian One Sample T-Tests

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre-Instruction Accuracy	5.27	19	< .001	578.2	5.05e-10	1.177

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post-Instruction Accuracy	1.47	16	.160	0.620	2.14e-4	0.357

Bayesian Linear Regression

Bayesian Factor Model Summary

Models	P(M)	P(M|data)	BF_M	BF_{10}	p-statistic	R^2
Null Model	.5	8.29e-7	8.29e-7	1	0	0
Accuracy	.5	1	1.21e+6	1.21e+6	< .001	0.633

Appendix J: Trial 21 statistical analyses

Descriptives

	N	Mean	Median	SD	SE
Pre (Close) Accuracy	4	73.6	72.2	8.33	4.17
Post (Close) Accuracy	4	88.9	91.7	7.86	3.93
Pre (Close) Target Selection	4	44.4	44.4	14.3	7.17
Post (Close) Target Selection	4	16.7	16.7	4.54	2.27
Pre (Close) Target Selected First	4	26.4	19.4	16	4.54
Post (Close) Target Selected First	4	11.1	11.1	9.07	4.54

Bayesian One Sample T-Tests

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre (Close) Accuracy	-1.01	3	.389	0.265	748e-5	-0.503

Note. Alternative Hypothesis specifies that the population mean is less than 77.7778

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post (Close) Accuracy	2.82	3	.067	1.972	5.16e-6	1.411

Note. Alternative Hypothesis specifies that the population mean is less than 77.7778

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre (Close) Target Selection	3.10	3	.053	0.145	2.12e-5	1.55

Note. Alternative Hypothesis specifies that the population mean is different from 22.2223

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post (Close) Target Selection	-2.44	3	.093	0.473	4.22e-5	-1.22

Note. Alternative Hypothesis specifies that the population mean is different from 22.2223

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre (Close) Target Selected First	1.91	3	.151	0.823	1.21e-4	0.957

Note. Alternative Hypothesis specifies that the population mean is different from 11.1112

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post (Close) Target Selected First	0	3	1	1.12	7.83e-6	0

Note. Alternative Hypothesis specifies that the population mean is different from 11.1112

Appendix K: Mean Eye Movement Statistical Analyses

Bayesian Linear Regression

Target Selected

Models	P(M)	P(M|data)	BF_M	BF_{10}	p-statistic	R^2
Null Model	.5	0.00159	0.00160	1	0	0
Target Selection	.5	0.99841	626.39382	626.39	< .001	0.407

Target Selected First

Models	P(M)	P(M|data)	BF_M	BF_{10}	p-statistic	R^2
Null Model	.5	0.390	0.640	1	0	0
Target Selected First	.5	0.610	1.562	1.56	.049	0.109

Bayesian One Sample T-Tests

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre-Instruction Target Selection	7.64	20	< .001	68112	1.19e-10	1.668

Note. Alternative Hypothesis specifies that the population mean is different from 22.2223

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post-Instruction Target Selection	-1.91	14	.077	1.12	2.40e-4	-0.493

Note. Alternative Hypothesis specifies that the population mean is different from 22.2223

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Pre-Instruction Target Selected First	6.26	20	< .001	4975	1.49e-11	1.367

Note. Alternative Hypothesis specifies that the population mean is different from 11.1112

	Student's t	df	p-statistic	BF_{10}	Error %	Cohen's d
Post-Instruction Target Selected First	1.42	14	0.178	0.590	1.96e-4	0.367

Note. Alternative Hypothesis specifies that the population mean is different from 11.1112

Bayesian Peason Correlation Matrix

	BF_{10}	Accuracy	Target Selected	Target Selected First
Accuracy	Pearson’s r	-		
	p-value	-		
	BF_{10}	-		
Target Selected	Pearson’s r	-0.604	-	
	p-value	< .001	-	
	BF_{10}	626.69	-	
Target Selected First	Pearson’s r	-0.341	0.757	-
	p-value	.042	< .001	-
	BF_{10}	4.97	0.0374	-

Note. For all tests, the alternative hypothesis specifies that the correlation is negative.