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EXPERT'S EYE: PRESENTING EYE-MOVEMENT PATTERNS TO TRAIN VISUAL SEARCH IN COMPLEX GEOPHYSICAL DISPLAYS

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PROJECT DECLARATION

I declare that the research described in this project is my own work, and that the report submitted is an original manuscript. All data reported are original and were collected as specified in the research methodology. Where exceptions exist to this declaration, these have been appropriately acknowledged in the report.

In accordance with Department of Psychology policy, I declare that this work has undergone an appropriate ethical review process prior to the conduct of the study.

I declare that the total word count is: 4940 words.

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ABSTRACT

Trainability of visual search strategies on coloured displays and the impact of perceptual uniformity of the colour scale were assessed. Participants were asked to search for four targets in red-white-blue (RWB) displays while their eye movements were recorded. These displays were mainly composed of distracting noise and were designed to correspond to spatial frequencies traditionally encountered in geophysical data images. The present study replicates previous findings that perceptual uniformity is a necessary prerequisite for the spontaneous application of a colour-based search strategy in RWB displays. It is further demonstrated that the application of this strategy is even more pronounced when novice participants are trained with eye-movement patterns of an expert in geophysical data images. Half of the participants were therefore shown video recordings of the gaze position of an expert scanning the displays whereas the other half was shown a static presentation of the images. This brief training session of approximately 6-7 minutes was shown to encourage the use of a colour based search strategy on uniform displays whereas it had no effect for non-uniform displays. It was also shown to increase the search speed slightly but regardless of the colour scale used. The enhanced application of the search by colour strategy after training with eye-movement patterns corroborates the use of uniform colour scales and provides an easy-to-implement training method for further improving visual search behaviour.

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Introduction

The search for natural resources is becoming more and more important to meet the growing demands of the world population. Therefore, increasingly sophisticated techniques are used to scan the earth for new deposits to allow further production. One possibility of coping with the massive amount of data that is produced by these scans is mapping the results to displays that are evaluated by a human professional (MacEachren & Taylor, 1994; Spence & Efendov, 2001; Spence, Kutlesa, & Rose, 1999). Assisting and facilitating the interpretation is thus one possibility to increase the effectiveness of geophysical scans that can yield benefits which cannot be achieved by technological and mechanical advancements.

The interpretation of images presenting data of seismic or geophysical scans is a complex and demanding task that involves visual search for specific patterns of colours and/or luminance values whereas every picture is mainly composed of distracting noise. A recently suggested possibility to facilitate the interpretation is the application of psychophysically scaled colour scales instead of commonly used scales (Donnelly, Cave, Welland, & Menneer, 2006; Welland, Donnelly, & Menneer, 2006). Psychophysically scaled colour displays aim at eliminating a specific bias that is inherent in the human visual system: the non-linear relation of physical colours and their psychological representation (Gregory, 1997). A specific wave length difference between two physical colours at different places on the colour spectrum consequently does not always imply an equal difference in the psychological representation. Psychophysically scaled colour displays therefore try to map data to images in a way that differences in the data give rise to corresponding differences in the psychological representation. Furthermore, specific biases such as context and similitude effects (De Valois & De Valois, 1997; Monnier & Shevell, 2003) that would affect the interpretation in non-uniform displays can be reduced (Hastie, Hammerle, Kerwin, Croner, & Hermann, 1996) The benefit of using these perceptually uniform displays instead of standard scales was evaluated in a recent study by Donnelly et al. (2006) with a focus on the utilisation of different search strategies.

In case of coloured geophysical displays which normally contain more than one target, two main strategies can be discriminated: search by proximity and search by colour. Search by proximity is conceptualised as trying to find targets of similar shape that are located nearby a previously found target whereas search by colour is based on looking for a target of the same colour as a previously found one. Regarding red-white-blue (RWB) displays, only a perceptually uniform scale was demonstrated to promote the use of search by colour. In other words: Perceptual uniformity seems to be a "necessary pre-requisite in order to usefully employ hue in search for a specific value" (Donnelly et al., 2006, p. 43). Thus, one way to assist the interpretation of seismic data images is mapping the data to perceptually uniform colour scales and thus enhancing the effectiveness of the search for geophysical resources.

The use of perceptually uniform displays is, however, not the only possibility to assist the interpretation of seismic data images. Accordingly, the present study aims at developing a further method of enhancing the effectiveness of visual search.

Most contemporary theories and models of visual search centre on the role of attention (e.g. Treisman, 1998; Treisman & Gelade, 1980; Wolfe, 1994). Although attention and its specific role in visual search behaviour have been conceptualised in various ways, most theories agree on the point that attention is a necessary prerequisite for a successful visual search when the targets are more complex than in a comparatively simple singleton/feature search. Additionally, there is a huge body of empirical findings in support of the premotor theory of attention (Rizzolatti, Riggio, Dascola, & Umilta, 1987), indicating that overt as well as covert attention is closely tied, if not identical, to the performance or at least the preparation of eye-movements (e.g. Deubel & Schneider, 1996; Nobre, Gitelman, Dias, Mesulam, 2000; Godjin & Theeuwes, 2003; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999).

Accordingly, the presentation of other people's gaze positions can be used to indicate where these people attended, or, in other words, how these people searched the displays (McCarley & Kramer, 2007). Furthermore, experts' eye-movements have been shown to differ systematically from novice eye-movements, either in terms of increased fixation numbers but decreased fixation duration (Rayner, 1998) or a reduced fixation number by constant fixation duration (Reingold, Charnes, Pomplun, & Stampe, 2001). Showing where an expert fixated can thus be employed as training when novices are asked to follow experts' eye-movements, especially as the mere performance of task-related eye-movements has been demonstrated to improve task performance (Thomas & Lleras, 2007).

Moreover, human beings seem to be prepared to learn from other people's gaze-directions (e.g. Richardson & Dale, 2005) and the social guidance of attention by gaze directions is a crucial aspect of human interactions. Thus, the understanding of other people's gaze direction develops early in human ontogeny (around 9 Months; Baron-Cohen, 1995; Carpenter, Nagell & Tomasello, 1998; Hood, Willen, & Driver, 1998) and continues to play an important role in social interactions. Consequently, adults retain the tendency to follow other person's gaze positions reflexively (Driver et al., 1999; Friesen, Moore, & Kingstone, 2005; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002), even if they know that the gaze position has no meaning for them (Friesen & Kingstone, 1998). These findings are corroborated by neuroimaging studies indicating that the reflexive allocation of attention to gaze positions is a unique form of reflexive orienting that is guided by highly specialized cortical areas (Friesen & Kingstone, 2003a, b; Grosbras, Laird, & Paus, 2005; Hoffman & Haxby, 2000; Perret et al., 1985). Taken together, there is a huge body of evidence suggesting that gaze directions and eye-movements are a useful method of directing the allocation of attention and thus assisting a variety of different tasks if employed in a proper way.

The presentation of expert's eye-movement patterns as training for novices has already been applied to different settings, including aircraft inspection tasks (Sadasivian, Greenstein, Gramopadhye, & Duchowski, 2005), the solving of programming problems (Stein & Brennan, 2004), and the scanning of x-ray images (Litchfield, Ball, Donovan, Manning, & Crawford, 2008). These studies reported effects on error rate, search times as well as the trainee's eye-movements. However, the results are not clear cut. For instance, the presentation of expert's eye-movements has been shown to increase search times in the aircraft inspection task (Sadasivian et al., 2005) whereas it has been shown to decrease search times in other settings (e.g. Stein & Brennan, 2004). This heterogeneous pattern might result from different ways of presenting the eye-movements (e.g. static vs. dynamic), whereas a dynamic presentation seems to be most useful to direct attention (Nalanagula, Greenstein, & Gramopadhye, 2006).

The present experiment's primary goal is the application of training with dynamic eye-movement patterns to assist the interpretation of geophysical images. For this purpose, a group of participants was shown the eye-movement patterns (i.e. a video of the fixation positions) of an expert scanning a set of geophysical displays. The performance of this group was compared to the performance of a group that was shown the search displays without eye-movement patterns. During the training session, participants were either told to follow the eye-movement patterns or watch the displays passively to develop a strategy to improve their performance (image preview group). To ensure a high ecological validity, participants were first accustomed to the displays (familiarisation phase). Then, eye-movement patterns (vs. images) were shown in a separate training phase which was followed by a test phase without further training.

In the familiarisation phase and test phase, participants were asked to search through displays containing four targets (coloured diamonds; see Figure 1) and four distractors while their eye-movements were recorded. They indicated the detection of a target by pressing a button on a gamepad while looking at the respective target. Participants' eye-movements were recorded in every phase.

Additionally, the issue raised by Donnelly et al. (2006) of using different colour scales was reassessed (perceptual uniform vs. non-uniform scales). Therefore, one half of the participants searched through displays with a per

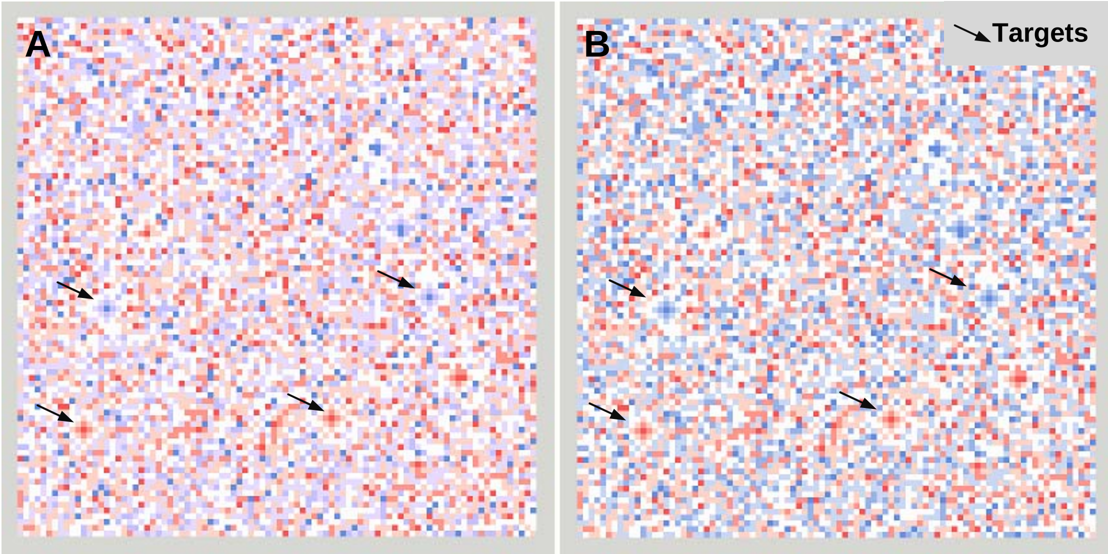

Fig. 1. Sample displays with 4 targets (symmetrically coloured diamonds) and 4 distractors in a uniform RWB-scale (U-RWB; Fig. 1A) and a non-uniform RWB-scale (N-RWB, Fig. 1B). Colours in this figure only approximate those obtained on the CRT.

ceptually uniform RWB-scale (Fig. 1A) and the other half searched through displays with standard non-uniform RWB-scale (Fig. 1B).

As both variations were implemented as between-subjects factors, the experiment consisted of four experimental groups: (a) uniform RWB-displays with image preview training, (b) non-uniform RWB-displays with image preview training, (c) uniform RWB-displays with training by eye-movement patterns, and (d) non-uniform RWB-displays with training by eye-movement patterns.

In accordance with the findings of Donnelly et al. (2006) it is hypothesized that the uniform RWB-scale gives rise to the application of the search by colour strategy whereas the non-uniform RWB-scale gives rise to faster completion times. Additionally, training with eye-movement patterns is hypothesized to produce faster completion times than training with images. This should be reflected in the eye-movement data where either fewer fixations or reduced fixation duration should be observed (or both). The effect size, however, is expected to be of a smaller magnitude as the study did not imply extensive training like it would be carried out in a real world setting and is thus likely to be a conservative estimate of the true effect size.

Two competing hypotheses can be derived for the impact of training on the search strategy. If the participants imitate the search strategy used by the expert (50% search by colour) the application of search by colour should be unaffected for uniform displays and enhanced for non-uniform displays (Donnelly et al., 2006). If, however, training with eye-movement patterns fosters the spontaneous trend, it should enhance the use of search by colour on uniform displays and even reduce it on non-uniform displays.

The training method can thereby be rated as effective if it is either able to reduce completion times (i.e. increase the search speed) or leads to a more pronounced application of the search by colour strategy.

Method

Participants

Forty participants (23 female) were recruited and either received course credits or participated voluntarily. The mean age was 28.50 years (SD = 13.80) and did not differ significantly between the experimental groups ($F(3, 36) = 0.24$, $p = .995$). All participants reported normal colour vision and normal or corrected-to-normal 20/20 vision and did not have previous experience with geophysical data images.

Apparatus

Eye movements were monitored using an EyeLink II tracker (SR Research Ltd., Osgoode, Canada). For each participant, one eye was monitored with a sampling rate of 250 Hz (registering pupil and corneal reflections). The eye which showed the smaller average error during the calibration of the tracker (0.20°-0.54°) was monitored, whereas individual calibrations were performed for familiarisation phase, training phase, and test phase. Stimuli were presented on a 17'' CRT monitor with a resolution of 1152 X 864 pixels and a refresh rate of 75 Hz. Responses were collected with one button of a Microsoft Sidewinder game pad (Microsoft Corporation, Berkshire, United Kingdom) which was pressed with the index finger of the left hand.

Material

The search displays were based on the stimuli used by Donnelly et al. (2006) and Spence and Efendov (2001). Each display measured about 24 ° x 24 ° as measured from a viewing distance of 60 cm and consisted of four targets, two at each end of the colour scale. The targets (1.7 ° x 1.7 °) formed a diamond shape with centre point at one end of the colour scale, and surrounding colours progressing along the scale to the mid-point of the scale (see Figure 1). Additionally, every display contained four distractors four distractors which were made up of the same colours as targets but with the spatial arrangement of the colours scrambled.

Two versions of each display were created to contrast a perceptually uniform red-white-blue scale (U-RWB) and a non-uniform red-white-blue scale (N-RWB). Each colour scale consisted of seven colours that were derived from Munsell colour space (Donnelly et al., 2006; Indow, 1988; Spence & Efendov, 2001; see Figure 2) and were designed to span as much of the colour space as possible. The U-RWB scale was the same as the uniform RWB scale used by Donnelly et al. (2006). Accordingly, perceptual uniformity was based on a different set of participants and the present study used a different computer screen and video card, so that the scale should only be considered approximately perceptually uniform. For the N-RWB scale, intervening colours were taken from numerically equal steps in RGB-values between the end-points of the colour scale and its white midpoint. The white and background grey were determined according to the white point of the monitor.

Procedure

The experiment consisted of three parts. After explaining the procedure and calibrating the eye-tracker, participants were first familiarised with the task and the experimental setting. In this familiarisation phase, they were shown 10 displays with the first three displays containing only targets and dis-

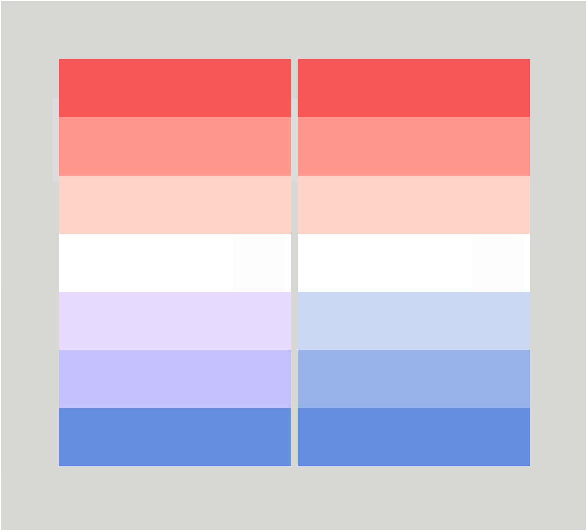

Figure 4. Red-White-Blue (RWB) scales used in the present experiment. The left colour scale is perceptually uniform (U-RWB) whereas the right colour scale is a traditional non-uniform scale (N-RWB). Colours in this figure only approximate those obtained on the CRT.

tractors and the remaining seven displays being similar to those shown in Figure 1. They were instructed to search through the display in every trial and try to locate the targets as quickly as possible. Every trial started with a fixation point that was used for eyetracker drift correction. After locating a target, participants pressed a button on the game pad while looking at the target. Button presses were counted as hit when the fixation point was in an 80 x 80 pixel (2 ° x 2 °) interest area around a target. Every trial ended as soon as all four targets had been found or after 60 s elapsed. The seven trials with complete displays also served as baseline measure for completion times (see Appendix I for a discussion on baseline measures of all other dependent variables).

After this familiarisation phase, the eye-tracker was re-calibrated and the participants received one of the two training methods. One half of the participants was shown the eye-movement patterns of an expert scanning 10 different displays. The eye-movement patterns were presented as a video overlay of the fixation point over the images. The videos started after an initial 10 s presentation of the display alone and ended as soon as the expert found all four targets. Participants were instructed to follow the fixation point to get an idea of “how an expert approaches these displays”. The second half of the participants was shown the same images for the same duration but without eye-movement patterns. They were instructed to sit back, defocus and try to adopt a strategy to become faster. No responses were collected in either group.

Finally, the impact of the training session was assessed in a test phase. Therefore, the eye-tracker was re-calibrated again and the participant searched through 36 displays. The trial procedure was the same as in the familiarisation phase and the 10 displays of the training phase were included in the 36 displays and were shown at random positions during the test phase (see Appendix II for a comparison of re-used and new displays).

The entire experiment took about 45 minutes to complete. Familiarisation and training phase each lasted about 10 minutes including instructions and the calibration of the eye-tracker so that the images were shown for about 6-7 minutes each. The test phase took about 20 minutes.

Results

The data of each participant were screened manually to exclude trials with obvious recording errors, especially trials in which the participant moved his eyes while carrying out a button press so that the gaze position could not be recorded correctly. 12.3% of the trials had thus to be excluded from data analysis. For the remaining trials, individual means of every participant were computed for the following dependent variables: (a) completion times, (b) button presses while looking at a distractor (distractor reactions), (c) number of fixations, (d) fixation duration, (e) percentage of fixations in interest areas around targets and distractors, and (f) the percentage of dwell time in these interest areas. Additionally, an index for search asymmetry and a search by colour index were calculated. The search asymmetry index was computed as proportion of trials where the first target to be found was red, the search by colour index as proportion of trials on which the second target or distractor found was of the same colour as the first target but not the nearest one.

Each dependent variable was subjected to a 2 (Training Type: images vs. eye-movement patterns) x 2 (Colour Scale: U-RWB vs. N-RWB) between-subjects ANOVA. A second ANOVA was conducted on the data of the familiarisation phase to control for baseline-differences in completion time.

To validate the data cleaning procedure described above, all analyses were computed a second time with a more conservative cleaning algorithm that only included trials where the number of button presses equalled the number of targets and distractors found. Both procedures led to the same overall pattern of results so that only the results of the first procedure are shown here.

Completion Times

The 2 (Training Type) x 2 (Colour Scale) ANOVA on the baseline measure of completion times showed a significant difference between the two colour scales with U-RWB giving rise to longer completion times than N-RWB (28.86 s vs. 19.97 s; $F(1, 35) = .8.88$, $p = .005$, $\eta_p^2 = 0.20$). No significant effects were found for Training Type or the interaction of both factors (both *F*'s < 1). However, only 39 data sets could be included in the analyses as one participant did not find all four targets in a single display before the trial timed out.

The same analysis on the data of the test phase showed an impact of Colour Scale, with U-RWB again giving rise to longer completion times than N-RWB (20.51 s vs. 13.91 s; $F(1, 36) = 5.651$, $p = .023$, $\eta_p^2 = 0.14$), and a slight tendency for Training Type with eye-movement patterns giving rise to faster completion times than image training (15.35 s vs. 19.07 s; ($F(1, 36) = 1.80$, $p = .188$, $\eta_p^2 = 0.05$). The interaction was still far from significant ($F(1, 36) = 0.04$, $p = .836$, $\eta_p^2 < 0.01$).

However, as a considerable number of trials ended before the fourth target had been found (up to 52% of an individual data set) the mean completion time cannot be taken as accurate estimate of the search speed. Therefore, a survival analysis (Cox regression) was conducted to include trials with timeouts. The regression model estimated the probability to find all four targets as a function of trial time, Colour Scale (U-RWB vs. N-RWB) and Training Type (image preview vs. eye-movement patterns). Both factors (Colour Scale and Training Type) as well as their interaction were entered in the model in one step. The resulting cumulative probability functions are shown in Figure 3.

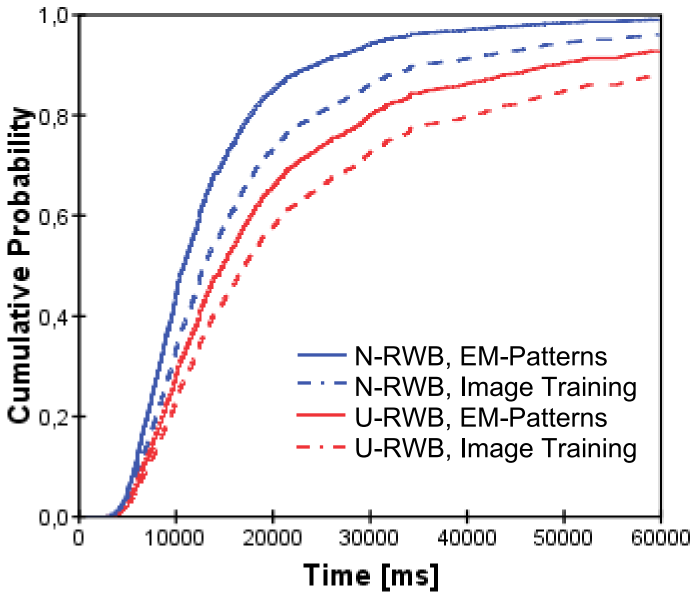

Figure 3. Estimated cumulative probability functions of the Cox Regression analysis by Colour Scale and Training Type (EM = Eye-Movements).

Both main effects were shown to be significant (Training Type: β = -0.36, $\chi^2(1) = 20.39$; $p < .001$; Colour Scale: β = -0.57, $\chi^2(1) = 48.19$; $p < .001$) whereas the interaction was not (β = -0.15, $\chi^2(1) = 1.55$; $p = .213$). Thus, participants were faster on non-uniform than on uniform colour scales and training slightly improved the speed regardless of the colour scale used. Additionally, neither Training Type (β = 0.04, $\chi^2(1) = 0.06$; $p = .802$) nor the interaction between Training Type and Colour Scale (β = 0.84, $\chi^2(1) = 0.12$; $p = .725$) reached significance in the same analysis for the familiarisation phase.

Distractor Susceptibility

The 2 x 2 ANOVA on mean distractor reactions revealed a significant influence of Colour Scale ($F(1, 36) = 8.44$, $p = .006$, $\eta_p^2 = 0.19$) with uniform scales giving rise to a higher distractor susceptibility than non-uniform scales (0.18 distractor reactions on average for U-RWB and 0.09 for N-RWB). Neither Training Type nor the interaction approached significance (both *F*'s < 1).

Search Strategy

Mean search by colour indices as proportion of trials where search by colour was exhibited are shown in Figure 4. With image training, the search index for the uniform scale was bigger than for the non-uniform scale. Training with eye-movement patterns increased the search index for uniform colour scales but decreased the search index for non-uniform scales.

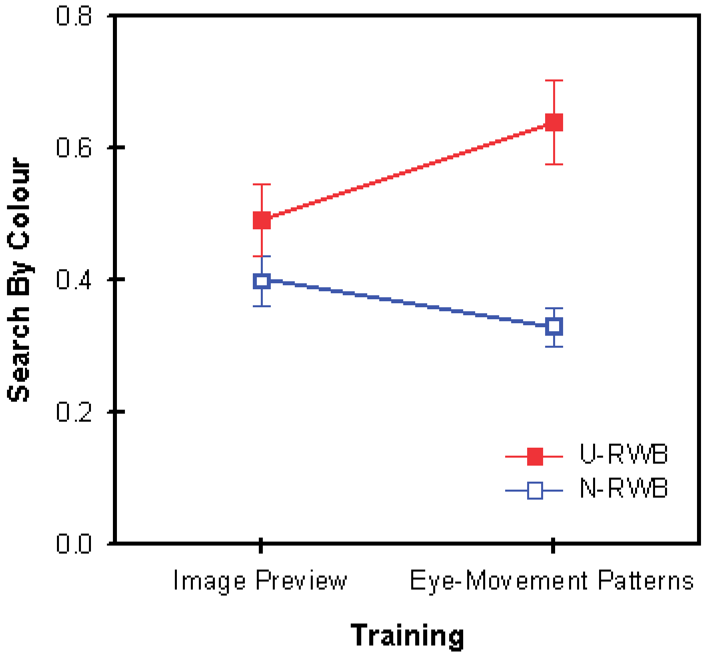

Figure 4. Mean proportion (+/- SE) of trials in which search by colour strategy was exhibited, i.e. the second target or distractor found was of the same colour but not closest to the first target found (chance probability: 16.67%).

The 2 x 2 ANOVA on search indices yielded a significant main effect of Colour Scale ($F(1, 36) = 17.228$, $p < .001$, $\eta_p^2 = 0.32$) and a significant interaction ($F(1, 36) = 5.02$, $p = .031$, $\eta_p^2 = 0.12$) whereas the main effect of Training Type was far from significant ($F(1, 36) = .664$, $p = .420$, $\eta_p^2 = 0.02$). Post-hoc tests revealed a marginal significant difference between the two training types for uniform displays ($t(18) = 1.76$, $p = .096$, $d = 1.76$) and a slight tendency for non-uniform displays ($t(18) = 1.45$, $p = .165$, $d = 1.45$).

Search Asymmetry

Mean search asymmetry indices as proportion of trials where the first target to be found was red are shown in Figure 5. Uniform displays gave rise to a higher search asymmetry than non-uniform displays. The search asymmetry was thereby enhanced by training via eye-movement patterns for uniform displays but unaffected for non-uniform displays.

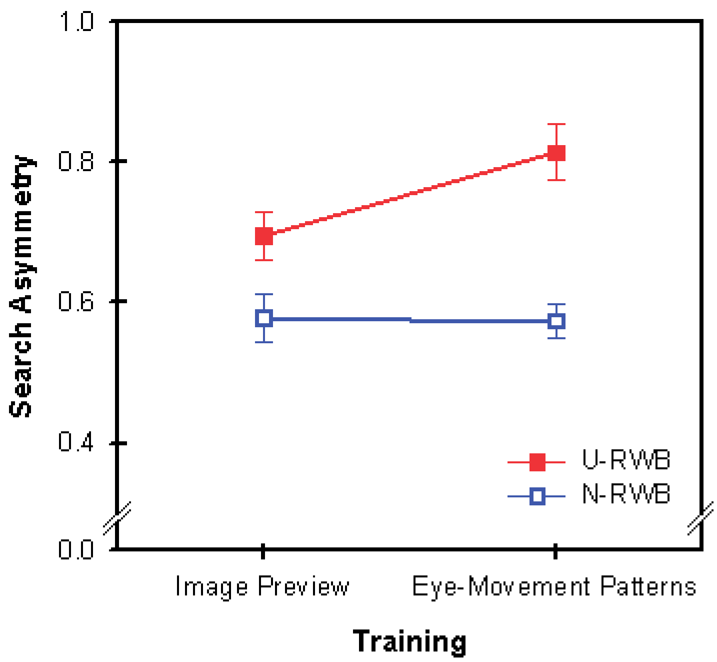

Figure 5. Mean proportion (+/- SE) of trials in which the first target found was red. Proportions > .5 indicate search asymmetry.

The 2 x 2 ANOVA on search asymmetry indices thereby yielded a significant main effect of Colour Scale ($F(1, 36) = 28.82$, $p < .001$, $\eta_p^2 = 0.45$). The main effect of Training Type ($F(1, 36) = 3.00$, $p = .092$, $\eta_p^2 = 0.08$) and the interaction ($F(1, 36) = 3.30$, $p = .077$, $\eta_p^2 = 0.08$) were shown to be of marginal significance. Exploratory post-hoc tests revealed a significant difference in search asymmetry for the two training types on uniform displays ($t(18) = 2.28$, $p = .035$, $d = 2.28$) but not on non-uniform displays ($t(18) = 0.07$, $p = .945$, $d = 0.07$).

Eye-Tracking Data

The mean number of fixations as a function of Training Type and Colour Scale is shown in Figure 6A. More fixations were registered for uniform scales than for non-uniform scales and training with eye-movement patterns decreased the number of fixations on both scales.

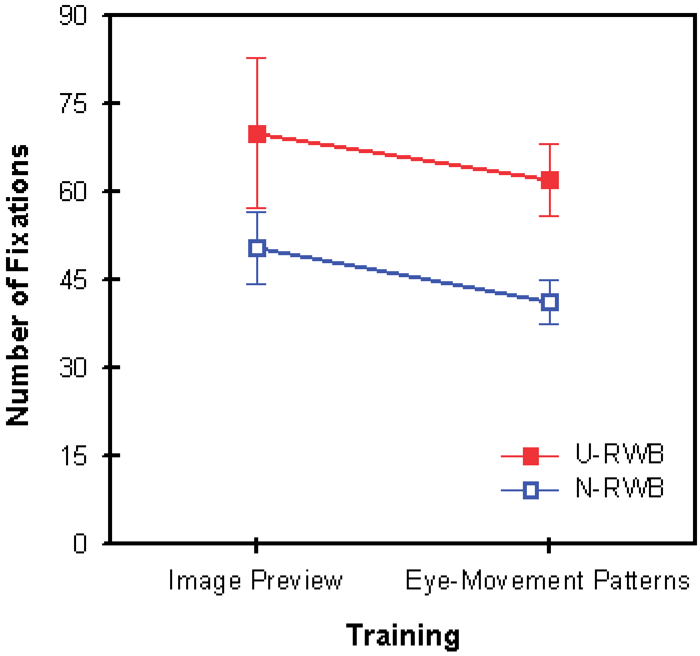

Figure 6. Mean number of fixations (+/- SE). The number of fixations is confounded with the varying trial duration in the four conditions (see Figure 3).

The 2 x 2 ANOVA on the number of fixations revealed a significant influence of Colour Scale (F(1, 36) = 6.45, p = .016, η_p^2 = 0.15). The main effect of training failed to reach significance (F(1, 36) = 1.15, p = .192, η_p^2 = 0.03) as well as the interaction (F(1, 36) = 0.01, p = .940, η_p^2 < 0.01). This pattern mirrors the effects reported for completion times of results but is, however, confounded with the trial duration. To arrive at a more robust estimation, the mean number of fixations per second was also subjected to the 2 x 2 ANOVA where none of the effects reached significance (all *F*'s < 1 with a mean number of 2.97 - 3.97 fixations per second).

Likewise, no significant influence of Training Type or the interaction was found on the mean fixation duration, percentage of fixations in interest areas around targets and distractors and the percentage of dwell time in these interest areas relative to the trial duration (all *p*'s > .214).

Discussion

The present study aimed at evaluating the presentation of experts' eye-movement patterns as a training method for visual search behaviour in complex geophysical displays. Additionally, possible benefits of perceptually uniform colour scales should be assessed.

Training with eye-movement patterns was thereby shown to increase the search speed slightly, regardless of the colour scale used. However, this effect was not as strong as the difference between the two colour scales, with completion times being longer for uniform displays than for non-uniform displays. The difference in completion times between the two colour scales is also mirrored in the eye-movement data, where fewer fixations were recorded for non-uniform displays. Regarding the search strategy used, the uniform colour scale (U-RWB) was shown to give rise to search by colour to a greater extent than the non-uniform colour scale (N-RWB). Training with experts' eye-movement patterns thereby increased the spontaneous application of search by colour on uniform displays but not on non-uniform displays. Additionally, uniform displays gave rise to a more pronounced search asymmetry with a tendency of red targets being found first – especially when participants were trained with eye-movement patterns.

These findings replicate previous results of the impact of different colour scales (Spence & Efendov, 2001; Donnelly et al., 2006) and extend them in several ways. First of all, the effect of perceptual uniformity on search strategy can be enhanced by training with a remarkable effect size. Search by colour is thereby an indicator of the search being guided by top-down mechanisms (Donnelly et al., 2006). This top-down application of a specific search strategy itself is a prerequisite for an effective search for a specific value in an image and is thus likely to improve performance on interpreting complex geophysical displays. However, these benefits seem to be accompanied by an increase in search asymmetry. This finding was previously explained in terms of the nature of the human visual system and its slower detection of blue targets in general (Mullen & Kingdom, 2002) which is increased by perceptual uniformity (Donnelly et al., 2006). It is thus likely that the colour based search strategy on uniform displays concentrated on easier to find red targets when starting to search through a trial.

In contrast, most eye-tracking variables – fixation duration, percentage of fixations on targets, percentage of dwell time on targets – remained uninfluenced by the type of training what contradicts previous findings (e.g. Litchfield et al., 2008). These differences, however, might result from the different format of eye-movement presentation, particularly blocked vs. trial-by-trial presentation. However, a qualitative reassessment of the eye-movement trajectories revealed that training with eye-movement patterns gave rise to more dispersed fixations. Image preview training on the other hand was followed by more sequential strategies as scanning the image row- or column-wise or circular eye-movement trajectories. These qualitative changes might reflect further top-down control of eye-movements. Qualitative changes in eye-movements might also account for the finding that the level of expertise of the person whose eye-movements are recorded does not influence the task performance (Litchfield et al., 2008). If the effect of training with eye-movement patterns effectively relies on these qualitative changes, the training method should be most useful for complete novices like in the present study. It is then likely to improve the learning curve for this low level of expertise whereas its use might be limited for users who already have some experience on the field. However, further studies with participants at different levels of expertise and long-term effects of the training method are required to test these conclusions.

Further applications and modifications of the present training method can be derived from gaze cueing paradigms (Frischen, Bayliss, & Tipper, 2007) and joint action research (Sebanz, Bekkering, & Knoblich, 2006). For instance, the physical presence of others and joint engagement in a task has been shown to have a special influence on attentional processes. First, joint engagement was demonstrated to automatically activate co-representations of the other's task (Sebanz, Knoblich, & Prinz, 2003, 2005) what could strengthen the association between observed eye-movement patterns and the own task. Second, the physical presence of others allows further cues to the focus of attention, like the appearance of the eye itself or the observation of head movements (Downing, Dodds, & Bray, 2004; Hietanen, 1999; Langton & Bruce, 1999; Langton, Watt, & Bruce, 2000). A brief training session where the expert's eye-movement patterns are presented online (i.e. while they are carried out by an expert who is physically present) might thus yield further benefits and are likely to enlarge the effect size of the present training method. Furthermore, a study comparing online presentation of eye-movements and similar training without information about the gaze position of an expert would be a more ecologically valid reassessment of the benefit of presenting eye-movement patterns.

Taken together, the present study demonstrated trainability of search strategy on complex geophysical displays by presenting the eye-movement patterns of an expert in this field. The increased utilisation of colours to guide the search was also accompanied by a slight decrease of search times. Given the effectiveness of the training in relation to its short duration, the present results justify an application of the training method on their own. Future directions of research might be the evaluation of the online presentation of eye-movements or the use of the method at different levels of expertise.

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Appendix I: Baseline Measures

Baseline measures for completion times were reported and discussed in the results section of the present report. Although only a small number of baseline trials were included in the study (7 per participants), these measures can still be taken as comparatively robust estimations of search speed as every completion time incorporates the search for 4 different targets. All other baseline measures should be treated with more caution and are therefore not included in the main report. Descriptives for every dependent variable and significance level of the according factors in a 2 (Training Type: image training vs. eye-movement patterns) x 2 (Colour Scale: U-RWB vs. N-RWB) between-subjects ANOVA are shown in Table A1.

Table A1. Descriptives and inferential statistical results for baseline measures.

	Training										
	Image View				Eye-Movements						
	RWB				**RWB**				**Significance Level**		
	Uniform		Non-Uniform		Uniform		Non-Uniform				
Dependent Variable	Mean	SE	Mean	SE	Mean	SE	Mean	SE	TT	CS	IA
Completion Time [s]	21.49	2.19	16.00	2.07	20.66	2.18	16.10	2.52	-	*	-
Distractor Reactions	0.28	0.09	0.08	0.03	0.37	0.13	0.16	0.05	-	*	-
Search Index	0.49	0.05	0.39	0.10	0.38	0.07	0.25	0.04	-	*	-
Search Asymmetry	0.71	0.04	0.59	0.06	0.71	0.07	0.49	0.06	-	-	-
Number of Fixations	75.29	11.20	61.15	6.28	82.30	10.32	54.18	8.34	-	*	-
Fixation Duration [ms]	386.95	16.61	328.51	20.12	342.63	20.07	360.18	24.59	-	-	-
% IA Fixations	0.58	0.02	0.59	0.02	0.62	0.03	0.62	0.03	-	-	-
% IA Dwell Time	0.85	0.07	0.91	0.01	0.92	0.00	0.92	0.01	-	-	-

* $p < 0.05$, - not significant. TT = Trial Type, CS = Colour Scale, IA = Interaction Trial Type x Colour Scale.

Appendix II: Reused Images

To assess the impact of re-using the image set of the training phase in the test phase, the data of the test phase were subjected to a 2 (Reuse: re-used image vs. new image) x 2 (Training Type: image training vs. eye-movement patterns) x 2 (Colour Scale: U-RWB vs. N-RWB) split-plot ANOVA for every dependent variable. The effects reported in the results section thereby seem to be robust to the influence of prior exposure as Reuse only reaches significance for two dependent variables (Table A2). It should, however, be noted that it also approached significance for completion times (p = .060), indicating that reused images were completed slightly faster than new ones.

Table A2. Differences in all dependent variables as a function of Reuse, Training Type, and Colour Scale. More distractor reactions and a higher search asymmetry were registered for reused images with a significantly lower search asymmetry for reused images after image training.

Dependent Variable	Significance Level			
	RE	RE x TT	RE x CS	RE x TT x CS
Completion Time [s]	-	-	-	-
Distractor Reactions	**	-	-	-
Search Index	-	-	-	-
Search Asymmetry	**	**	-	-
Number of Fixations	-	-	-	-
Fixation Duration	-	-	-	-
% IA Fixations	-	-	-	-
% IA Dwell Time	-	-	-	-

** p < .01, - not significant; RE = Reuse, TT = Training Type, CS = Colour Scale.